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A REPORT OF TEST RESULTS OF THE 94 GHz BIRD DETECTION RADAR (BIRDAR™) AT DFW AIRPORT

WaveBand Corporation

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13. ABSTRACT *(Maximum 200 Words)*

A 94 GHz radar was developed under the Dual Use Science and Technology (DUST) program sponsored by the Federal Aviation Agency and the U.S. Air Force, AFRL/SNRT. The radar was developed by WaveBand Corporation. The University of Illinois Center of Excellence in Airport Technology (CEAT) provided support for the testing and evaluation of the 94 GHz radar designated BIRDAR™ by the WaveBand Corporation. The radar system was tested at several locations in California, and a major testing campaign was conducted at the Dallas/Forth Worth International Airport (DFW), September 17-15, 2004. This report provides a report of radar testing conducted at DFW and the post-campaign analysis of test results conducted by CEAT and the U.S. Air Force.

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EXECUTIVE SUMMARY

As part of the Dual Use Science & Technology Program (DUST), the U. S. Air Force and the Federal Aviation Administration initiated Project SN-02, "Development of a Dedicated Bird Radar for Airports and Military Airfields." In the project, the effective detection of bird hazards focused on the development of a short range radar prototype that would direct data on bird detections to an airport information technology system. WaveBand Corporation in Irvine, California was the successful bidder for the development contract. WaveBand designed and constructed a 94 GHz radar (BIRDAR™). BIRDAR™'s specifications included a 3 mile detection range; altitude determination up to 3,000 ft.; a proven lack of interference with existing airport and FAA radar, landing system, and other equipment; and a capacity for integration into existing airport GIS systems.

A number of tests and field trials were held through 2003 and 2004 in preparation for a major test at the Dallas/Fort Worth International Airport (DFW) in September, 2004. The DFW testing campaign was initiated on September 13 with coordination meetings and initial radar deployment. In the following 11 days, the radar was tested at various locations on and near DFW airport. The detection program was opportunistic, focused on natural movement of birds within the detection range of the radar. Testing programs were designed to detect small birds in flocks of various sizes, medium sized birds in flocks or as individuals, and large sized birds singly or in flocks. The availability of bird targets limited testing to the first two categories; no large birds or flocks of large birds were present during the testing campaign.

The deployment at DFW was also intended to evaluate the operation of the radar in an airport operational environment and determine utility in recognizing hazards created by birds and other wildlife. Because testing was opportunistic based on wildlife movement on and around the airport operating area (AOA), detection testing required multiple deployments of the radar at different locations. Testing was conducted at times appropriate to bird activity, which was usually dawn and dusk, but included midday testing for raptors (e.g. hawks and vultures). In the testing campaign, a test was considered an observation sequence with a single objective, conducted to provide the needed data for radar evaluation. Multiple tests were performed each day, usually at dawn and dusk when bird activity was greatest. There were often multiple bird detections in a single test. Testing was also conducted during periods of high levels of aircraft movement.

Following the completion of testing, the test files (containing approximately 150 GB of radar data) were verified and then prepared for analysis. The verification process began with a coordinated review of the radar data by WaveBand and CEAT, where radar data that appeared to represent bird activity were flagged for verification. These data were then compared with logs of wildlife activity to see if the radar data matched the description given by the observers during testing (i.e. range, heading, altitude, number and type of birds). From the subset of radar data that were valid and had ground truthing information available, a number of individual detections were identified. The protocol developed for recording radar data and ground truthing supported an integrated analysis of the test results. Twenty-three independent detections were selected for analysis and assessment. These detections were a representative sample of the data, including different species, flock types, ranges, and radar orientations.

The radar hardware and support equipment performed well during the DFW field testing campaign. Operation of the radar was consistent and reliable. The support components including the trailer, associated equipment, and personnel functioned well. The protocols developed for this testing were determined to be sound, and provide a model for future testing. The data collection procedures were consistent, and good quality data was obtained. Although still under development, analysis procedures (Appendix A) have provided useful information about radar performance. The availability of raw data from the radar system will support future analysis and methods development.

Based on the data collected at DFW, the effective range for specific bird activities has been determined. Blackbird flocks were detected at up to 1,300 m, but at extreme ranges the signal was visible only if the operator was aware of the presence and general location of a target, and post-processing techniques were optimized for image enhancement. The upper effective detection range for flocks of blackbirds was 1,200 m, with 1,000 m being the upper detection limit at which bird flocks were consistently detectable using MTI processed images.

Raptor detection varied with the mass of the species. For example, the American kestrel mass averages 115 g, while hawks and vultures mass averages 1-1.5 kg. For these larger birds, which are the greater concern for flight safety, the upper detection range was 1,200 m. The detection limit for kestrels has not been determined, but is believed to be less than 500 m (based on the absence of radar detection for a confirmed sighting at 500 m).

Hawks and vultures were the largest birds present. Airport wildlife records indicate cormorants (1.8 kg) were present on site at the time of testing. Detection #13 may have been cormorants but independent observations at the time of radar testing for this detection are unavailable, so the use of this detection in radar evaluation will be limited. In addition to cormorants, other bird species regularly occur at DFW, such as Canada geese, which can weigh up to 6.6 kg. These large bird species were not present during the test campaign, but it is likely that they would have been detected at the ranges confirmed, with likely detection of flocks at up to 2.3 km based on other testing of the radar (Appendix B).

During the radar development, the radar was tested with bird targets on several other occasions. A summary of this additional testing is provided in Appendix B. For these trials, the emphasis was placed on radar system technology evaluation rather than bird detection following the test protocol used at DFW. In these trials, ground truthing of detections was limited or absent. Furthermore, hardware development occurred between these trials, which makes direct comparison with DFW results more complicated. However, the results of these trials are still valuable in bird detection analysis and should represent minimum detection capabilities that can be verified when future test campaigns include large mass bird species.

The Klamath testing detected a large flock of snow geese at 2.1 km, and many birds at closer range. The results from the Salton Sea demonstrated that individual pelicans were consistently visible at up to 1.6 km, and post-processing revealed individual bird signals at 2 km. While there is no record of the farthest flock detected in the field, post-processing detected flocks of large birds such as geese as far away as 2.3 km (plus a very weak signal at 2.6 km from a flock of 100 snow geese).

In December 2004, the U.S. Air Force Research Laboratory conducted additional analysis of the data collected during the Dallas/Fort Worth Airport (DFW) tests. As part of this analysis, moving target indicator (MTI) methods were applied using a moving average filter method and a cell averaging filter method. The moving average filter is intended to reduce the visibility of clutter, and a cell averaging filter is intended to reduce spikes in noise and lower the false alarm rate.

The Air Force analysis focused on two tests conducted as part of the DFW campaign. One test was conducted on September 22 to determine the detection range of BIRDAR™. In this test BIRDAR™ was oriented down a taxiway. The test included an attempt to put a trihedral retro-reflector (also referred to as a corner reflector) in the center of the radar beam, and with movement downrange, measure the falloff of the radar detection capability as the retro-reflector was moved in increments of about 500 meters. The distance from the radar to the corner reflector was verified using the total station. The radar performance closely matched the expected performance of the radar at ranges up to 1,500 meters where detection began to degrade slightly.

The second test used in the analysis was conducted at Trigg Lake, on September 15, 2004 from 7:09 a.m. to 7:15 a.m. A large flock of grackles, approximately 1,000, flew over Trigg Lake and was detected by the radar (Detection # 12, Section 3, page 7). This particular test was selected due to the availability of good ground truth data including multiple records of the location, number, and type of birds. The flock detected in this test was used for MTI processing developments and grackle radar cross section calculations. Signal-to-noise ratio (SNR) calculations were performed on this data. The results of these analyses gave an upper limit for the detection range with a required SNR of 0 dB. With a human operator to distinguish legitimate targets, the range predicted closely follows the observed detection ranges seen by the radar for a flock of birds the size of grackles. Automatic detection generally requires 10 or more dB SNR. The larger SNR will significantly reduce the detection range of the radar.

1. INTRODUCTION

As part of the Dual Use Science & Technology Program (DUST), the U. S. Air Force and the Federal Aviation Administration initiated Project SN-02, "Development of a Dedicated Bird Radar for Airports and Military Airfields." In the project, the effective detection of bird hazards focused on the development of a short range radar prototype that would direct data on detections to an airport information technology system. WaveBand Corporation in Irvine, California was the successful bidder for the development contract. WaveBand designed and constructed a 94 GHz radar (BIRDAR™). BIRDAR™'s specifications included a 3 mile detection range; altitude determination up to 3,000 ft.; a proven lack of interference with existing airport and FAA radar, landing system, and other equipment; and a capacity for integration into existing airport GIS systems.

A number of tests and field trials were held through 2003 and 2004 in preparation for a major test at the Dallas/Fort Worth International Airport (DFW) in September, 2004.

The objectives of the testing campaign at DFW Airport were to:

i. Ensure that the radar can detect and track bird targets at distances commensurate with those needed for bird detection at airports and airfields,

ii. Display their movement on the monitor, and

iii. Display the bird targets on a computer containing a GIS.

The DFW testing campaign was initiated on September 13 with coordination meetings and initial radar deployment. In the following 11 days, the radar was tested at various locations on, and near, DFW airport. The detection program was opportunistic, focused on natural movement of birds within the detection range of the radar. Testing programs were designed to detect small birds in flocks of various sizes, medium sized birds in flocks or as individuals, and large sized birds singly or in flocks. The availability of bird targets limited testing to the first two categories; no large birds or flocks of large birds were present during the testing campaign. This report provides initial analysis of the data collected as part of the DFW BIRDAR™ testing.

2. MATERIALS AND METHODS

2.1 TEST EQUIPMENT

BIRDAR™ was provided by the WaveBand Corporation and is described in their reporting to the DUST program. CEAT provided logistic support and provided review and direction to the bird detection testing based on the wildlife and biological monitoring expertise in CEAT. A major component of CEAT's logistic support was the development of a field laboratory support facility in the form of a 16 ft. utility trailer (Figure 2-1).

FIGURE 2-1. THE TRAILER USED TO HOUSE THE RADAR FOR THE DFW TEST. THE ANTENNA IS THE WHITE RECTANGULAR OBJECT VISIBLE ON THE LEFT SIDE OF THE TRAILER.

Radar and data recording equipment were installed in the trailer and a systems test was performed at WaveBand's facilities in Irvine, CA prior to the DFW testing. The trailer provided a 7 ft. x 16 ft. enclosed workspace. Access to the trailer workspace was through a door on the starboard side; double swing doors provided access to the rear of the trailer where the radar was mounted. The rear opening was enclosed in transparent plastic; the left half of the opening used ¼ in. Plexiglas, while the right half used a radar-transparent 1/8 in. polycarbonate material. A 3,000 W generator provided the primary power through a 20 amp service. This portable electrical service provided power to the radar and associated computers, lighting, and to a HVAC unit providing cooling.

The trailer served to protect the radar, control and data recording equipment, and personnel from inclement weather, and to serve as a platform on which to mount the BIRDAR™ system. The BIRDAR™ system included: a radar antenna, transmitter, and receiver; a computer to control the radar parameters and to provide data acquisition and data processing; a power distribution module; a video camera and S-VHS video recorder; an azimuth position rotator and control; and compass and inclinometer measuring devices. The radar was mounted in the trailer on the equipment racks. Jacks provided trailer stability, which leveled and stabilized the trailer for radar operation. A three axis adjustment on the equipment racks provided fine adjustment of radar orientation. The racks accommodated the radar with the long dimension of the antenna in either the vertical or horizontal direction.

The video camera was boresighted with the radar antenna. The camera horizontal field was adjusted to correspond to the radar scan angle of 30 degrees. The radar antenna elevation beam width of ±1.25 degrees was marked on the monitor to facilitate correlation between radar imagery and the field of view captured by the video camera.

Test support equipment included radio communication devices, tools, personal conveniences, voice recorders, a supplementary camcorder, pocket PCs with GIS and GPS support, log books, and a total station for distance measurement to 3,500 m with an error of less than 1 cm and accurate angle measurement for elevation determination.

2.2 FIELD TEST PROCEDURES

In addition to the primary testing objectives, the deployment at DFW was also intended to evaluate the operation of the radar in an airport operational environment and determine utility in recognizing hazards created by birds and other wildlife. Because testing was opportunistic based on wildlife movement on and around the AOA, detection testing required multiple deployments of the radar at different locations. Location selection was made based on test objectives. Testing was conducted at times appropriate to bird activity, generally dawn and dusk, but including midday testing for raptors. In this protocol, a test is considered a single objective evaluation conducted to provide the needed data for radar evaluation. Multiple tests were performed each day, usually at dawn and dusk when bird activity was greatest. There were often multiple bird detections in a single test. Testing was also conducted during periods of high levels of aircraft movement. Each test had a stated specific objective, such as attempting to determine the maximum range at which blackbird flocks can be detected, or detecting raptors at various ranges.

2.2.1 Field Test Protocol

Each test used the following protocol:

1. The trailer with mounted radar was moved to the site selected for the test. The trailer was leveled and stabilized, generator set up and power and voltage levels verified. Before the radar was powered on, DFW Operations and the FAA were notified, so that in the event of any unforeseen interference they would be aware of the radar activity. A WAAS

enabled GPS measurement was made to establish the location of the trailer. This measurement was made at the hitch of the trailer. Location was verified by reference to the DFW GIS. In addition to location, the orientation/bearing of the trailer axis was recorded (as measured by the compass mounted onto the antenna, a handheld magnetic compass, and the total station). If the trailer was set up at a site where testing had already been conducted, a new site number was assigned for that test to reflect the unintentional differences in setup that may have occurred.

2. If the antenna had a different orientation than that of the trailer, the difference was measured by the antenna-mounted compass. The radar detection area was then verified for that location. The verification involved the placement of trihedral retroreflectors with 1020 m^2 RCS (radar cross section) at the edges of the radar field of view. The reflectors were placed at a minimum distance of 500 ft. from the radar, except when the AOA or landscape features prevented it. Distance to the retroreflectors was determined using the radar and total station. Elevation was calculated by the total station using the measured distance and angle from the radar to the target, and verified by the GPS on the pocket PC. Other measurements that give the radar orientation are the compass and pitch values that can be recorded from the rotator on which the radar is mounted (when it scans in the horizontal direction) and the instruments mounted on the radar. If the azimuth or pitch needed to be adjusted slightly during the calibration or testing, the change was measured and logged.

3. For the bird verification tests, the personnel always included the following three tasks: a radar operator, a radio communications coordinator and identification specialist (in the trailer), and a downrange wildlife identification specialist from DFW. For almost all of the tests, additional personnel included: a second downrange wildlife identification specialist, a video recorder of bird flocks at the trailer, an operator of the total station to measure elevation of bird flocks, and supplementary wildlife spotters at the trailer. All personnel had access to a radio to facilitate rapid communications. The three identification specialists also had audio voice recorders, pocket PCs (using ArcPad for data entry), and paper logs to record bird activity. Data recording protocols provided a time stamp on the radar data files, video records, audio records, paper logs, and pocket PC logs. When the radar was powered down, DFW and FAA personnel were notified.

4. All data acquired during the test was verified using the radar post-processor software and an electronic backup of the radar data was created. The other data collected was backed up daily.

One full calibration of the radar was completed, where the trihedral retroreflector was placed at 500 m increments from the radar, up to 2 km. At each location, the signal strength was measured, and the pitch of the antenna was varied to see how the signal varies away from the center of the beam.

2.2.2 Support Data Acquisition

Data sheets were prepared to provide a consistent data acquisition system for the DFW testing. For each test, a brief narrative was prepared to describe the test objective, test location, general test conditions, and all records of test protocol calibration and verification measurements. Data sheets contained the names and location of all computer files generated during the test.

2.2.3 Radar Data Acquisition

During each test, the length of files was limited to 6 minutes. All files for a given session used the same naming convention, which indicated the site location, test series, and file number for that site and series. The data was organized into folders by date and time of day.

2.2.4 Wildlife Observation Records

Observation records were kept using several redundant methods. When possible, observers would use ArcPad to enter the wildlife location, along with relevant information (date/time, species, number of animals, direction of travel, elevation, and other notes). When there was too much bird activity to enter all data in this fashion, paper logbooks were used. The paper log also contained the name of the observer, the observer's location in relation to the radar, and any other notes. Audio recorders were used to record all communication and observations. Audio recording is ideal as a backup, since it leaves the hands free to use binoculars and is very rapid. All observations were time stamped, and all time measurements were synchronized. In many cases, several observers reported the same wildlife occurrence. The objective of these observations was to establish species and movement paths of all birds in the radar field of view.

The information on the forms was transcribed to an Excel spreadsheet. In addition to records of visual observations, downrange observers were in radio contact with radar test personnel to provide real-time observation data that was used to verify radar detection capability. Observers provided information on species, number, direction of travel, distance from radar, and time interval for moving birds, allowing the radar personnel to determine whether or not the signal was visible. Conversely, observed radar signals were reported to wildlife spotters to draw their attention to birds they may not have seen otherwise.

2.2.5 Radar Data Recording and Field Processing

All test data were recorded onto the radar computer, then two backups were made to high capacity portable hard drives. Processed data files were named with a convention that referred to individual tests and the processing performed. The radar test data were processed by CEAT personnel and displayed with a spatial resolution appropriate to the radar field of view. Test data were also processed for use in the DFW GIS developed by the Center of Excellence.

2.3 TEST LOCATIONS

The testing campaign was initially approved for a limited number of locations and a limited azimuth to prevent interference with existing radar and other airport-related electronics. On the first day of testing on the airport operations area (AOA), a test was conducted with the cooperation of local FAA personnel to verify the lack of interference with critical airport systems. This test verified no interference with existing airport facilities and approval was granted to place the radar more opportunistically and orient the radar freely. Before any testing, DFW and FAA personnel were notified, and at the conclusion of testing another notification was given. Figure 2-2 provides the location and approximate view of the BIRDAR™ during the DFW testing.

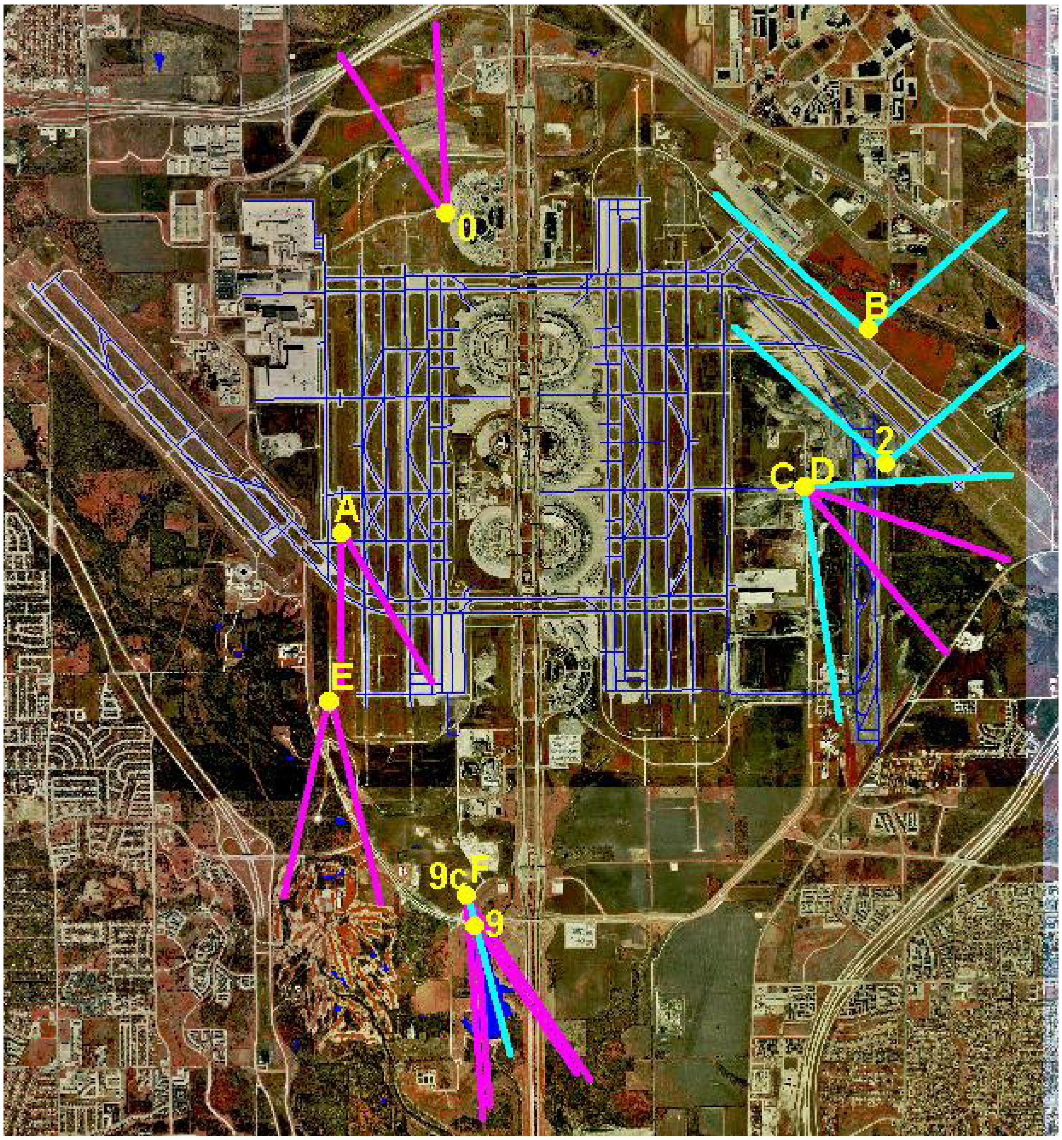

FIGURE 2-2. BIRDAR™ TEST LOCATIONS AND ORIENTATION DURING THE DFW TESTING CAMPAIGN. PINK INDICATES HORIZONTAL ORIENTATION, BLUE INDICATES VERTICAL ORIENTATION.

2.4 RADAR DATA ASSESSMENT AND ANALYSIS PROCEDURE

Following the completion of testing, the test files (containing approximately 150 GB of radar data) were verified and then prepared for analysis. The verification process began with a coordinated review of the radar data by WaveBand and CEAT, where radar signals that appeared to be bird activity were flagged for verification. If the signal was sufficiently strong for analysis, the logs of wildlife activity were then consulted to see if the radar signal matched the description given by the observers during testing. From the subset of radar data that was both clearly visible and had ground truthing information available, a number of individual detections were identified. The analysis for these detections followed a protocol that provided an integrated analysis of individual test results. An illustrated version of this protocol is available in Appendix A. The following is the analysis/assessment protocol used for each detection:

1. Detection:
   A bird signal was first identified by reviewing the radar data in the post processor at high speed. The high speed made it more efficient to look for birds, and noise became less apparent relative to detections. Once a signal was identified, if it was weak, it was viewed several times to be sure that it was a positive detection rather than semi-ordered noise. When the signal was confirmed, the file name, frame number, and approximate distance to the signal were entered into a radar log in Excel. The type of signal (approximate size, flock type, and length of time it was visible) was logged as well.

2. Verification:
   Once a signal had been found, it was viewed with the MTI (moving target indicator) mode to see if it is still readily viewable. This mode of the post processor filters out static unchanging background signals, and allows the moving detections to be isolated. It also allows data to be exported into tabular format, which is not possible in the raw mode.

   The settings used were static average, with a threshold of 15 dB. The threshold determines how strong the signal has to be; a high threshold filters out more noise, but also will cause some loss of the desired signal. For the weak signals that were not apparent at this level, the threshold was adjusted to a lower level (down to as low as 10) to see if it was detectable at all in MTI mode, and if so, how much background noise was present. If it is impossible (or practically impossible) to see the signal in MTI, the signal was logged as not viewable in MTI. If it was viewable, but only at a threshold under 15, it was logged as marginally viewable in MTI.

3. Identification:
   To confirm the type and number of birds detected, the first step was to figure out the time of signal. The starting time of the radar file will be correct, but time then progresses in the post processor at approximately twice the speed of real-time, so a rough estimate of actual time can be calculated. Once the time of the flock was determined, the paper logs, audio logs, and PDA logs were consulted to see what information (if any) was available about bird activity at that time. Since all watches and device clocks were synchronized, it was fairly straightforward to determine what information was available. Information about the bird detection, as well as what sources the information came from, was logged.

For detections where the sole purpose of analysis was to confirm that it was bird activity, and to describe the detection in great detail, no further assessment was carried out after this point.

4. Display:
   Any flock of serious interest was exported through the MTI to a dbf file so that the data could be analyzed. If the display was zoomed in on the post-processor to show the signal in greater detail, only the data within that window was exported (limiting file size and processing time). The dbf file was then imported to an Access database, and a SQL query was used to transform the radial coordinates into Cartesian coordinates. The modified dbf was used to create a GIS file that allowed both display and interactive measurement/analysis in a visual format.

   For a full analysis, the non-flock returns (noise) were manually deleted from the MTI data, one second at a time in the GIS. This is especially important for the display of weak signals that were exported with a low threshold value, or when the data needs to be in tabular format for analysis. The result is a dbf file with range, azimuth, magnitude, and time/date information for all flock returns.

   If the data were vertical (and the radar was fixed), display in GIS was much more complex. First, before filtering, the data were displayed as if it was horizontal (in a 30 degree horizontal cone) so that all of the data at different heights was distinct, instead of layered into a 2.5 degree wide cone. The data were manually filtered, then transformed back into a 2.5 degree wide cone; with the noise removed, the signal was visible, otherwise it was completely obscured. This was achieved by adding coordinates to the data for the 2.5 degree cone centerline and edges. Height could then be shown with different colors if desired. If the data were recorded in vertical mode, but with the radar being manually moved back and forth to follow raptors, it is not meaningful to display the results in GIS, as no record was kept of precisely how the antenna was moved.

5. Measurement:
   The next step was to pinpoint range information: what the maximum range was at which the flock was visible, what the size of the flock was, and how the mean range changed over time. This information was used to determine how a single flock's signal changes, from both natural fluctuations and changing range. This was accomplished by going through the raw data using the post processor, and recording minimum and maximum visible range of the flock every few frames (by clicking on the pixels at the near and far edges in the post processor, which displayed the range). In this fashion, the distance and size of the flock were recorded over time. The elevation of the flock at each point was calculated from the range and the known elevation angle of the radar beam.

6. Analysis:
   The final step for selected returns was to examine the isolated dbf file containing only bird returns. This made it possible to start to see how much natural variation there was

from second to second in the radar returns at a constant distance, and how much change in signal strength and pattern was evident as the mean range of the flock changed.

The raw radar data measurements of flock distance from the measurement section were plotted on a graph (minimum, maximum, and mean distance from the radar) to provide an indication of how the flock was moving and how the detected size of the flock changes over time. Another graph of flock size over time was plotted to indicate how much variability was present in the returns. For most signals, the birds were traveling perpendicular to the beam, so the ‘size’ being measured was actually flock width. To pinpoint where the flock was in 3-D, the minimum, maximum, and mean elevation of the radar beam was calculated for the mean range of each flock measurement. The volume of a radar cell at the mean range of each flock measurement was calculated as well. If the flock moved through a runway approach path, a plane’s expected elevation on approach at the relevant area was determined.

To look for patterns that examined how signal strength changes over distance and time, graphs were created showing: magnitude vs. distance, magnitude vs. time, and number of returns vs. time. To try to reduce natural variation, the data were also analyzed by second (combining several frames of data); mean magnitude (by second) vs. time and sum magnitude (by second) vs. time are plotted. The magnitude distribution was plotted to estimate typical values for the flock and to determine range.

3. RESULTS

3.1 DAILY OVERVIEW OF TEST RESULTS

Calibration and bird detection testing were conducted from September 13 through September 24. The following is a log of daily activity:

Monday, 9/13:

Evening:

The trailer was set up at the north side of Trigg Lake looking south (site 9). The majority of the bird activity was flocks of blackbirds moving to the SE at close-medium range. No ground truthing was carried out, as for this first test the focus was solely on getting the radar operation procedures to go smoothly.

Detections:

- Multiple single birds at 100 m
- 2 small blackbird flocks at 1 km, marginably viewable with MTI
- 1 blackbird flock at 1.3 km, very weak signal, not viewable with MTI
- Multiple dense streaming blackbird flocks and smaller spherical blackbird flocks at 200-700 m

Tuesday, 9/14:

Morning:

The majority of activity was flocks of blackbirds moving to the NW at close-medium range, similar to the day before but moving in the opposite direction.

Detections:

- Multiple single birds at 100 m (mainly blackbirds)
- Several small groups of blackbirds from 200-300 m
- 2 weak small groups of blackbirds at 500 m
- 2 medium-small linear blackbird flocks from 100-225 m (the larger one was 500 starlings)
- Multiple streaming blackbird flocks (both wide/dense and thin/diffuse) and smaller spherical blackbird flocks from 200-500 m

Evening:

The trailer was moved to the construction site farther from Trigg Lake, still overlooking the lake (site 9c).

Detections:

- A few single birds present at close range
- Light rain caused difficulty in seeing much of anything.
- Heavy rain essentially incapacitated the radar, except at extremely close range.

Wednesday, 9/15:

Morning:

Detections:

- Multiple single or small groups of blackbirds at close range

Evening:

The trailer was moved to site 0 (the first site on the AOA, NE of site 1, near the N end of taxiway H). For this initial test we aimed the radar well clear of the ASR-9 to the northeast.

Detections:

- Small flock of unidentified birds at 1.5 km, marginably viewable with MTI. There are no logs of this bird flock, but the signal appears to be too strong to be blackbirds. One possibility is a small group of cormorants (mass about 1.6 kg/ea), which we saw a few of in the area on other days. This was the farthest bird flock detected during the testing at DFW.

Thursday, 9/16:

Morning:

The interference test was run with the ASR-9 radar. The radar radiated while directly aimed at the antenna for 5 minutes, varying pitch and azimuth of the antenna after a while to ensure the aim was correct. No interference was detected, and as such permission was granted to operate the radar at sites not previously cleared for our use by the FAA. Afterwards the radar was aimed to the north to look for birds. Wildlife activity was unusually light for this site, according to DFW staff.

Detections:

- Short range individual birds and small flocks

Evening:

The trailer was moved to site A roughly at the intersection of taxiway WM and D (SE of runway 13R/31L). Blackbird flocks were visually observed at distances of 1.5-2.5 km, but none were seen by the radar

Friday, 9/17:

Morning:

Detections:

- Blackbird flocks were present at distances of 1.5-2.5 km (according to visual observations at the trailer and downrange reports from DFW personnel), none seen by radar

Midday:

The trailer was moved to site 2 with the goal of attempting long-range raptor detection. The radar was operated with the antenna in the vertical mode. Since the goal of this test was to determine if it was possible to see raptors at long range, the antenna was manually moved back and forth to track the raptors present. Since raptors move extensively through 3-dimensions, a fixed orientation generally only captures very limited activity. For the duration of raptor testing, DFW personnel attempted to chase birds into our field of view.

Detections:

- Lots of soaring birds present at 1.5-3 km (seen from trailer and by downrange spotters), none seen by radar.

Saturday, 9/18:

Midday:

The trailer was moved to site B to be closer to the expected raptor activity.

Detections:

- Multiple hawks and vultures, mostly 400-550 m.
- Difficulty tracking birds may have prevented longer detections

Sunday, 9/19

This day was used for data processing, backup, and meetings. No testing was carried out.

Monday, 9/20:

Midday:

The trailer was moved to site C on the taxiway EL bridge. A camcorder with a strong zoom was mounted to the antenna to help track birds with the antenna at long range. Most of the day was done with vertical orientation (manually scanning back and forth), but the horizontal orientation was tested later on.

Detections:

- Several soaring birds (hawks and vultures) from 300 m to 1.2 km
- Two hawks at 1.5 km were not visible
- For horizontal orientation, no birds entered the beam within range.

Tuesday, 9/21:

Midday:

The trailer had to be moved off of the taxiway after the test on Monday 9/20, but an attempt was made to locate at the same site this day. This attempt to situate at site C was labeled site D. The radar was operated in the horizontal orientation for several hours of testing, followed by a brief vertical orientation run.

Detections:

- Two soaring birds in the horizontal orientation (it was difficult to get raptors to fly into the horizontal beam)
- One soaring bird in the vertical orientation

Evening:

The trailer was relocated to site E, at the south end of taxiway C. Most blackbirds were not within the beam within detection range; they were either too far or too low. The bird activity was also very light in general. No significant detections were made.

Wednesday, 9/22:

Morning:

Blackbirds detected at 700 m, although most of the birds were still most likely not in the beam. One or two large flocks were visually observed at 1.2-1.3 km at a height that appeared to be in the radar beam, but were not detected by the radar.

Thursday, 9/23:

Evening:

The trailer was moved to the construction site overlooking Trigg Lake, referred to as site F (close by site 9c). This site was chosen for a demonstration as part of a press conference. This particular location was used because it reliably has large groups of wildlife, which increased the likelihood of being able to show the press positive detections. The press conference prevented personnel from recording logs of wildlife activity, but the radar recorded several blackbird flocks from 300-700 m

Friday, 9/24:

Morning:

The radar was operated in a fixed vertical-orientation setup for the first time.

Detections:

- Several blackbird flocks seen by radar at range of 500 m-1.1 km.

3.2 SUMMARY OF SIGNIFICANT DETECTIONS

The radar record was reviewed following this protocol for analysis/assessment, and twenty-three independent test results were selected. These detections are meant to serve as a representative sample of the data, including different species, flock types, ranges, and radar orientations. A summary of these detections is provided in Table 1.

TABLE 3-1: TEST DETECTION RESULTS

Detection ID	Site	Date	Time	Duration	Bird Species/Type	Number	Flock Type	Range, m	Elevation, ft.	Orientation
1	9	9/14	7:22	34	Starlings		large dense	350-590	100	horizontal
2	9	9/14	7:23	32	Starlings		large diffuse	500-615	100	horizontal
3	9	9/14	7:23	43	Starlings		linear flock	275-575	100	horizontal
4	9	9/14	7:25	32	Blackbirds	2000	linear flock with gaps	260-400	200	horizontal
5	9	9/14	7:25	34	Starlings	50	smaller clumps	230-400		horizontal
6	9	9/14	7:26	203	Starlings	5000	thick linear flock	260-475	100	horizontal
7	9	9/14	7:29	39	Blackbirds		intermittent clumps	380-570		horizontal
8	9	9/14	7:30	41	Starlings	500	thick flock	250-480		horizontal
9	9c	9/14	18:36	10	Starlings	150	small	1150-1200	150	horizontal
10	9c	9/14	18:38	19	Starlings	175	small	950-1100	200	horizontal
11	9c	9/14	18:43	14	Starlings	300	med thin linear	100-170		horizontal
12	9c	9/15	7:11	43	Grackles	1000	large dense	600-1000	150	horizontal
13	0	9/15	19:02	37	Unidentified		small	1450-1550		horizontal
14	A	9/17	7:39	19	Grackles/starlings mixed	30	small	985-1050		horizontal
15	B	9/18	12:44	25	Turkey vulture	1	n/a	115-300	100-150	vertical(mobile)
16	B	9/18	12:47	120	Turkey vulture	1	n/a	220-710	20-535	vertical(mobile)
17	B	9/18	13:37	25	Hawk	1	n/a	200-300	20-70	vertical(mobile)
18	C	9/20	9:40	90	Hawk	2	n/a	615-1000	175-305	vertical(mobile)
29	D	9/21	11:23	40	Turkey vulture	1	n/a	650-850		horizontal
20	D	9/21	11:25	35	Turkey vulture	2	n/a	875-1100		horizontal
21	E	9/22	7:18	16	Grackles	500	large dense	785-850		horizontal
22	F(9c)	9/24	7:25	66	Starlings	2000	large thin linear	100-750		vertical(fixed)
23	F(9c)	9/24	7:27	38	Starlings	1000	large thin linear	835-1300		vertical(fixed)

The following narratives are summaries of the test detection results:

Detection #1:
At site 9, a large dense flock of starlings was detected at 07:22 on 9/14/04. The flock was spread out from 350 to 590 meters from the radar, traveling west at an elevation of 100 feet above ground level (AGL). The flock was visible for 34 seconds with the radar in horizontal orientation. Identification of the signal is available on one paper log (at the trailer).

Detection #2:
At site 9, a large diffuse flock of starlings was detected at 07:23 on 9/14/04. The flock was spread out from 500 to 615 meters from the radar, traveling west at an elevation of 100 feet AGL. The flock was visible for 32 seconds with the radar in horizontal orientation. Identification of the signal is available on one paper log (at the trailer).

Detection #3:
At site 9, a thin linear flock of starlings was detected at 07:23 on 9/14/04. The flock was about 30 meters wide, and moved between 575 to 275 feet from the radar, traveling west/northwest at an elevation of 100 feet AGL. The flock was visible for 43 seconds with the radar in horizontal orientation. Identification of the signal is available on one paper log (at the trailer).

Detection #4:
At site 9, an intermittent thin linear flock of 2,000 blackbirds was detected at 07:25 on 9/14/04. The flock varied from 20 to 50 meters wide, and moved between 400 to 260 meters from the radar, traveling west/northwest at an elevation of 200 feet AGL. The flock was visible for 32 seconds with the radar in horizontal orientation. Identification of the signal is available on one PDA log (downrange) and one paper log (at the trailer).

Detection #5:
At site 9, several small groups of blackbirds (comprising about 50 birds total) were detected at 07:25 on 9/14/04. The flock varied from 20 to 60 meters wide, and moved between 400 to 230 meters from the radar, traveling west/northwest. The flock was visible for 34 seconds with the radar in horizontal orientation. Identification of the signal is available on one audio log (at the trailer) and one paper log (at the trailer).

Detection #6:
At site 9, a thick linear flock of 5,000 starlings was detected at 07:26 on 9/14/04. The flock varied from 30 to 70 meters wide, and moved between 475 to 260 meters from the radar traveling between west and northwest at an elevation of 100 feet AGL. The flock was visible for 203 seconds with the radar in horizontal orientation. Identification of the signal is available on one audio log (at the trailer), one PDA log (at the trailer), and one paper log (at the trailer).

Detection #7:
At site 9, several small flocks of blackbirds were detected at 07:29 on 9/14/04. The flock varied from 15 to 50 meters wide, and moved between 570 to 380 meters from the radar, traveling west/northwest. The flock was visible for 39 seconds with the radar in horizontal orientation.

Identification of the signal is available on one audio log (at the trailer) and one paper log (at the trailer).

Detection #8:
At site 9, a thick linear flock of 500 starlings was detected at 07:30 on 9/14/04. The flock varied from 30 to 80 meters wide, and moved between 480 to 250 meters from the radar, traveling west/northwest. The flock was visible for 41 seconds with the radar in horizontal orientation. Identification of the signal is available on one audio log (at the trailer) and one paper log (at the trailer).

Detection #9:
At site 9c, a small flock of 150 starlings was detected at 18:36 on 9/14/04. The flock was 20 meters wide, and moved between 1,200 to 1,150 meters from the radar, traveling northeast at an elevation of 150 feet AGL. The flock was visible for 10 seconds with the radar in horizontal orientation. Identification of the signal is available on one PDA log (downrange) and one paper log (at the trailer).

Detection #10:
At site 9c, a small flock of 175 starlings was detected at 18:38 on 9/14/04. The flock was 25 meters wide, and moved between 950 to 1,100 meters from the radar, briefly traveling northeast then turning sharply to the south at an elevation of 200 feet AGL. The flock was visible for 18 seconds with the radar in horizontal orientation. Identification of the signal is available on two audio logs (at the trailer and downrange), one PDA log (downrange) and one paper log (at the trailer).

Detection #11:
At site 9c, a thin linear flock of 300 starlings was detected at 18:43 on 9/14/04. The flock was about 45 meters wide, and moved between 170 to 100 meters from the radar, traveling west/northwest. The flock was visible for 14 seconds with the radar in horizontal orientation, during fairly heavy rain. Identification of the signal is available on one audio log (at the trailer) and one paper log (at the trailer).

Detection #12:
At site 9c, a very large dense flock of 1,000 grackles was detected at 07:11 on 9/15/04. The flock was spread out from 600 to 1,000 meters from the radar, traveling west at an elevation of 150 feet AGL. The flock was visible for 43 seconds with the radar in horizontal orientation. Identification of the signal is available on two audio logs (at the trailer and downrange), two PDA logs (at the trailer and downrange), and two paper logs (at the trailer and downrange).

Detection #13:
At site 0, a small flock of unidentified birds was detected at 19:02 on 9/15/04. The flock was about 35 meters wide, and moved between 1,550 to 1,450 meters from the radar, traveling east/southeast. The flock was visible for 37 seconds with the radar in horizontal orientation. No ground truthing identification of the signal is available, but based on the signal strength and range, and the wildlife present at DFW, it is hypothesized that it may have been a flock of

double-crested cormorants. This was the farthest bird detection at DFW airport during the testing period.

Detection #14:
At site A, a small flock of 30 blackbirds (mixed grackles and starlings) was detected at 07:39 on 9/17/04. The flock was about 15 meters wide, and moved between 985 to 1,050 meters from the radar, traveling south/southeast. The flock was visible for 19 seconds with the radar in horizontal orientation. Identification of the signal is available on two audio logs (at the trailer and downrange), two PDA logs (at the trailer and downrange), and three paper logs (one at the trailer and two downrange).

Detection #15:
At site B, a single turkey vulture was detected at 12:44 on 9/18/04. The vulture circled between 115 and 300 meters from the radar at an elevation of between 100 and 150 feet AGL. The bird was tracked for 25 seconds by manually rotating the radar in vertical orientation to follow the bird. Identification of the signal is available on one audio log (downrange), one PDA log (downrange), and one paper log (at the trailer).

Detection #16:
At site B, the same single turkey vulture from detection #15 was detected again at 12:47 on 9/18/04. The vulture circled between 220 and 710 meters from the radar at an elevation of between 20 and 535 feet AGL (slowly circling higher). The bird was tracked for 120 seconds by manually rotating the radar in vertical orientation to follow the bird. Identification of the signal is available on one audio log (downrange), one PDA log (downrange), and one paper log (at the trailer).

Detection #17:
At site B, a single hawk was detected at 13:37 on 9/18/04. The hawk circled between 200 and 300 meters from the radar at an elevation of between 20 and 70 feet AGL. The hawk was tracked for 25 seconds by manually rotating the radar in vertical orientation to follow the bird. Identification of the signal is available on one audio log (at the trailer) and one paper log (at the trailer).

Detection #18:
At site C, two hawks were detected at 09:40 on 9/20/04. The hawks circled between 615 and 1,000 meters from the radar at an elevation of between 175 and 305 feet AGL (slowly circling higher). The bird was tracked for 90 seconds by manually rotating the radar in vertical orientation to follow the bird. Identification of the signal is available on one audio log (at the trailer) and one paper log (at the trailer).

Detection #19:
At site D, a single turkey vulture was detected at 11:23 on 9/21/04. The vulture circled between 650 and 850 meters from the radar at an elevation of between 65 and 150 feet AGL. The bird was tracked for 40 seconds with the radar in horizontal orientation. Identification of the signal is available on one audio log (at the trailer) and one paper log (at the trailer).

Detection #20:
At site D, two turkey vultures were detected at 11:25 on 9/21/04. The vultures circled between 875 and 1,100 meters from the radar at an elevation of between 65 and 150 feet AGL. The birds were tracked for 35 seconds with the radar in horizontal orientation. Identification of the signal is available on one audio log (at the trailer) and one paper log (at the trailer).

Detection #21:
At site E, a medium-sized dense flock of 500 grackles was detected at 07:18 on 9/22/04. The flock was about 40 meters wide, and moved between 785 to 850 meters from the radar traveling west. The flock was visible for 16 seconds with the radar in horizontal orientation. Identification of the signal is available on one audio log (downrange) and two paper logs (at the trailer and downrange).

Detection #22:
At site F, a thick linear flock of 2,000 starlings was detected at 07:25 on 9/24/04. The flock varied from 60 to 90 meters wide, and moved between 100 to 750 meters from the radar traveling northwest at an elevation of between 35 and 90 feet AGL. The flock was visible for 66 seconds with the radar in fixed vertical orientation. Identification of the signal is available on two audio logs (both downrange), one PDA log (downrange), and three paper logs (one at the trailer and two downrange).

Detection #23:
At site F, a thin linear flock of 1,000 starlings was detected at 07:27 on 9/24/04. The flock was about 40 meters wide (according to the radar: due to the long range the flock may not be detected at the edges), and moved between 835 to 1,300 meters from the radar traveling northwest at an elevation of between 50 and 90 feet AGL. The flock was visible for 38 seconds with the radar in horizontal orientation. Identification of the signal is available on two audio logs (both downrange), one PDA log (downrange), and three paper logs (one at the trailer and two downrange).

4. AIR FORCE RESEARCH LABORATORY ANALYSIS OF DATA

In December 2004, the U.S. Air Force conducted an independent analysis of the data collected during the Dallas/Fort Worth Airport (DFW) tests. The analysis focused on two tests. One test was conducted with the BIRDAR™ pointed down a taxiway. There was an attempt to put a retro-reflector (also referred to as a corner reflector) in the center of the radar beam and measure the falloff of the signal level as the corner reflector was moved down the taxiway and away from the radar in increments of about 500 meters. The distance from the radar to the corner reflector was verified using the total station.

The second test used in the analysis was conducted at Trigg Lake, on September 15, 2004 from 7:09 a.m. to 7:15 a.m. A large flock of grackles, approximately 1,000, flew over Trigg Lake and was detected by the radar (Detection # 12, Section 3, Page 7). This particular test was selected due to the availability of good ground truth data including multiple records of the location, number, and type of birds. This flock was used for MTI processing, development of grackle radar cross section calculations, and signal-to-noise calculations. Figures 4.1 and 4.2 show a view of where the radar was pointed and a representative picture of what the flock looked like respectively.

FIGURE 4-1. PICTURE OF TRIGG LAKE FROM THE VIEWPOINT OF THE RADAR.

FIGURE 4-2. REPRESENTATIVE PICTURE OF THE FLOCK FLYING OVER TRIGG LAKE.

4.1 RECONSTRUCTION OF POST PROCESSOR DISPLAY

To make the results easier to understand and comparable to the results produced by WaveBand, the post processor display was recreated in Matlab. A matrix of size 4096 by 90 is created in Matlab and filled with the raw data. When the radar scans and creates a frame, it scans in 90 increments of one-third of a degree each, for a total angular coverage of 30 degrees. For each scan, 4096 samples are taken. These samples represent the measured frequency difference at a given time. The frequency difference provides a continuous wave (CW) tone, corresponding to the range of the target. The range profile of the returns is generated by taking the Fast Fourier Transform (FFT). This process is illustrated in Figure 4.3. The raw data was passed through a Blackman filter of size 4096 before performing the FFT to eliminate some of the high frequency noise. After the FFT, the resulting matrix represents range bins by angle bins. The value in each bin represents the magnitude of the return the radar received. Before the data was stored by the hardware, however, it was passed through a filter to make all the targets appear at the same magnitude. Otherwise, targets farther out in range would be masked by strong near-in returns.

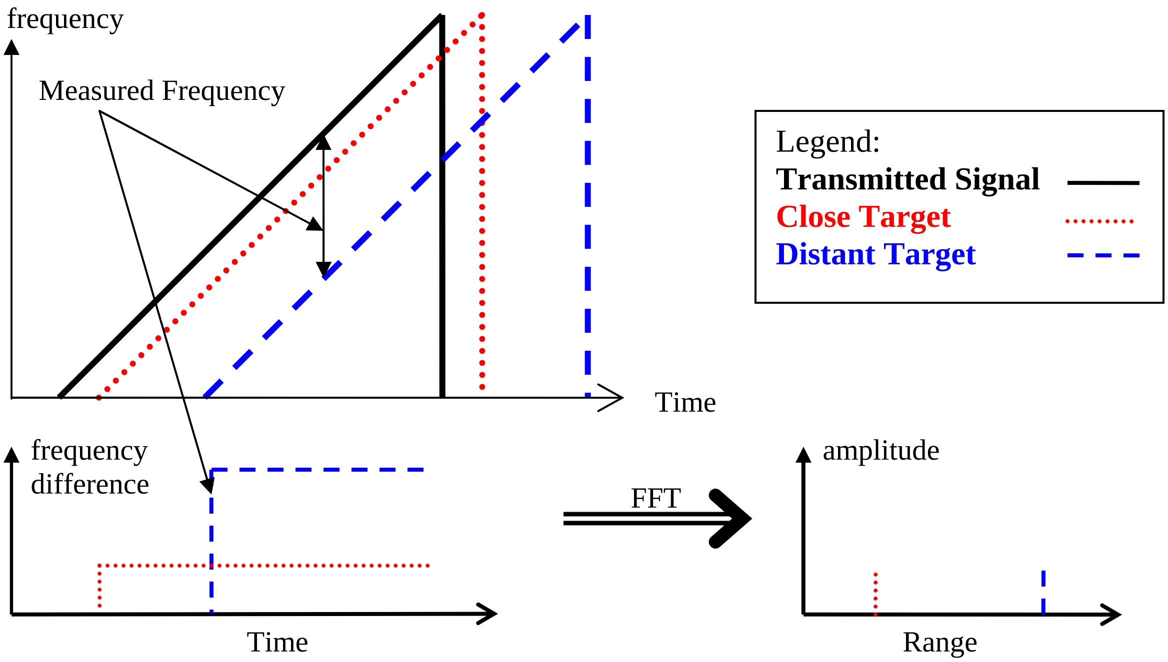

FIGURE 4-3. POST PROCESSOR ALGORITHM.

4.2 MOVING TARGET INDICATOR (MTI)

After recreating the display, a few basic moving target indicator (MTI) plots were generated. The goal of an MTI is to eliminate clutter (stationary objects) from the display and highlight only moving targets. Two types of filters were created: a moving average filter to reduce the visibility of clutter, and a cell averaging filter to reduce noise spikes and lower the false alarm rate.

4.2.1 Moving Average Filter

A moving average filter uses information from previous frames to subtract stationary clutter from the current frame being viewed. In the MTI for BIRDAR™, the previous frames are averaged together and then subtracted from the current frame on a cell by cell basis. The equation and a visual representation are shown in Figure 4.4.

F_1 F_2 F_3 F_4 F_5 F_6 F_7 F_8 F_9 F_{10}

$$Average_i = \left(\frac{1}{N}\right)\sum_{k=i}^{N} F_k$$

Output$_i$ = F$_i$ – Average$_{i-1}$
Output$_9$ = F$_9$ – Average$_8$
Output$_{10}$ = F$_{10}$ – Average$_9$

FIGURE 4-4. MOVING AVERAGE FILTER.

The number of frames, N, used in the average is determined by the user. The more frames used, the slower the filter adjusts to changes in the environment (i.e. a flock of birds flying), the better the noise is reduced, and the better the MTI performs for this radar. More frames in the average, however, requires more memory to store previous frames but not more processing power or computational time. If there are not enough frames in the average, the target(s) will be subtracted out of the current frame as if they were clutter. This is illustrated in Figures 4.5 through 4.7. Figure 4.5 shows frame by frame subtraction (N=1) on the left and no MTI on the right. The frame by frame subtraction shows the fluctuations in the noise and subtracts off most of the signal generated from the flock of birds. The red circles highlight the leading edge of the flock of birds. The MTI generates only a small group of white dots to represents the flock and shows a great deal of noise.

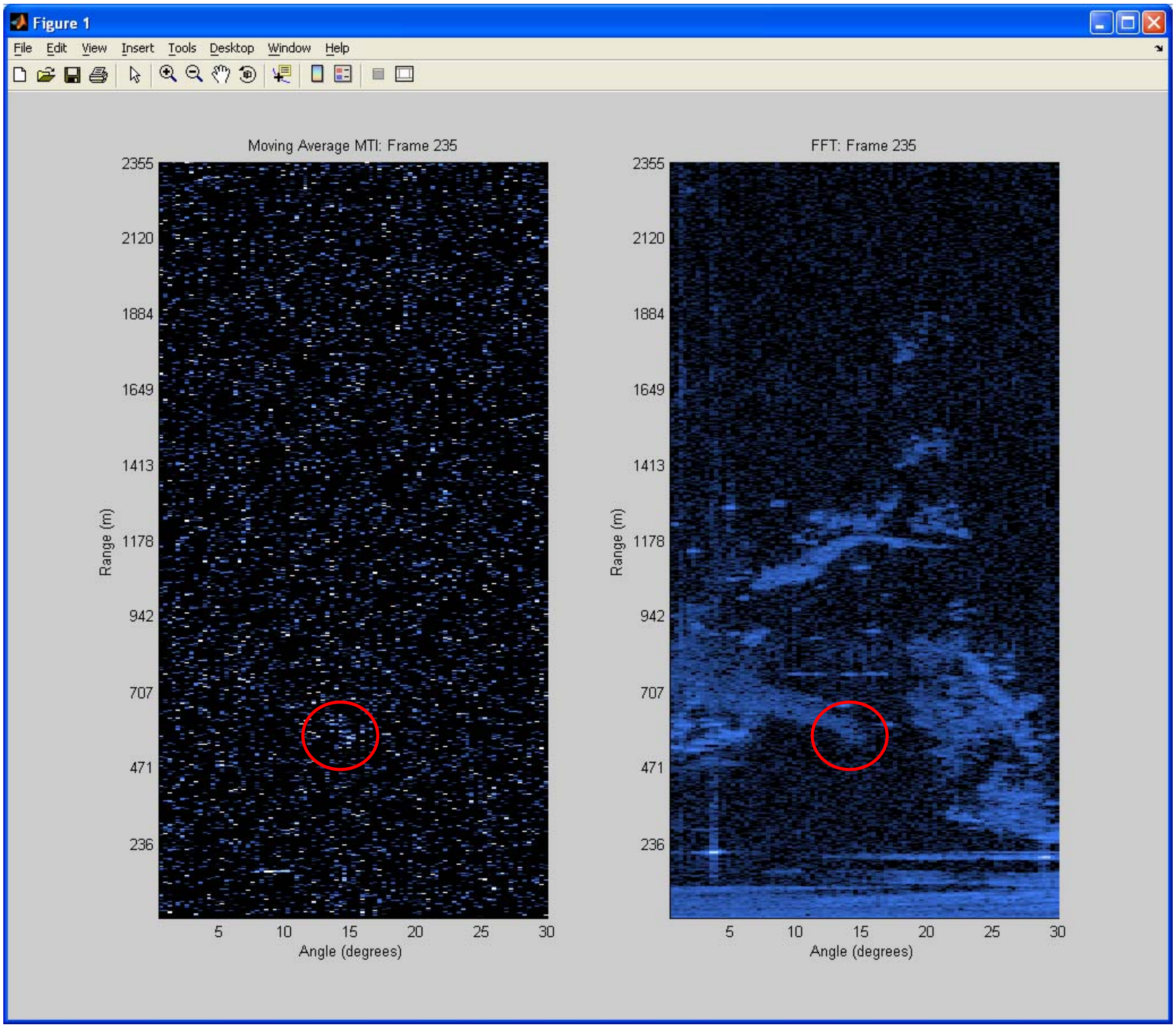

FIGURE 4-5. LEFT: MTI WITH N=1. RIGHT: RADAR IMAGE OF THE FLOCK FLYING OVER TRIGG LAKE.

In Figure 4.6, N was increased to 10. The flock begins to become more evident although much of the flock is being subtracted off. The noise level has also been reduced.

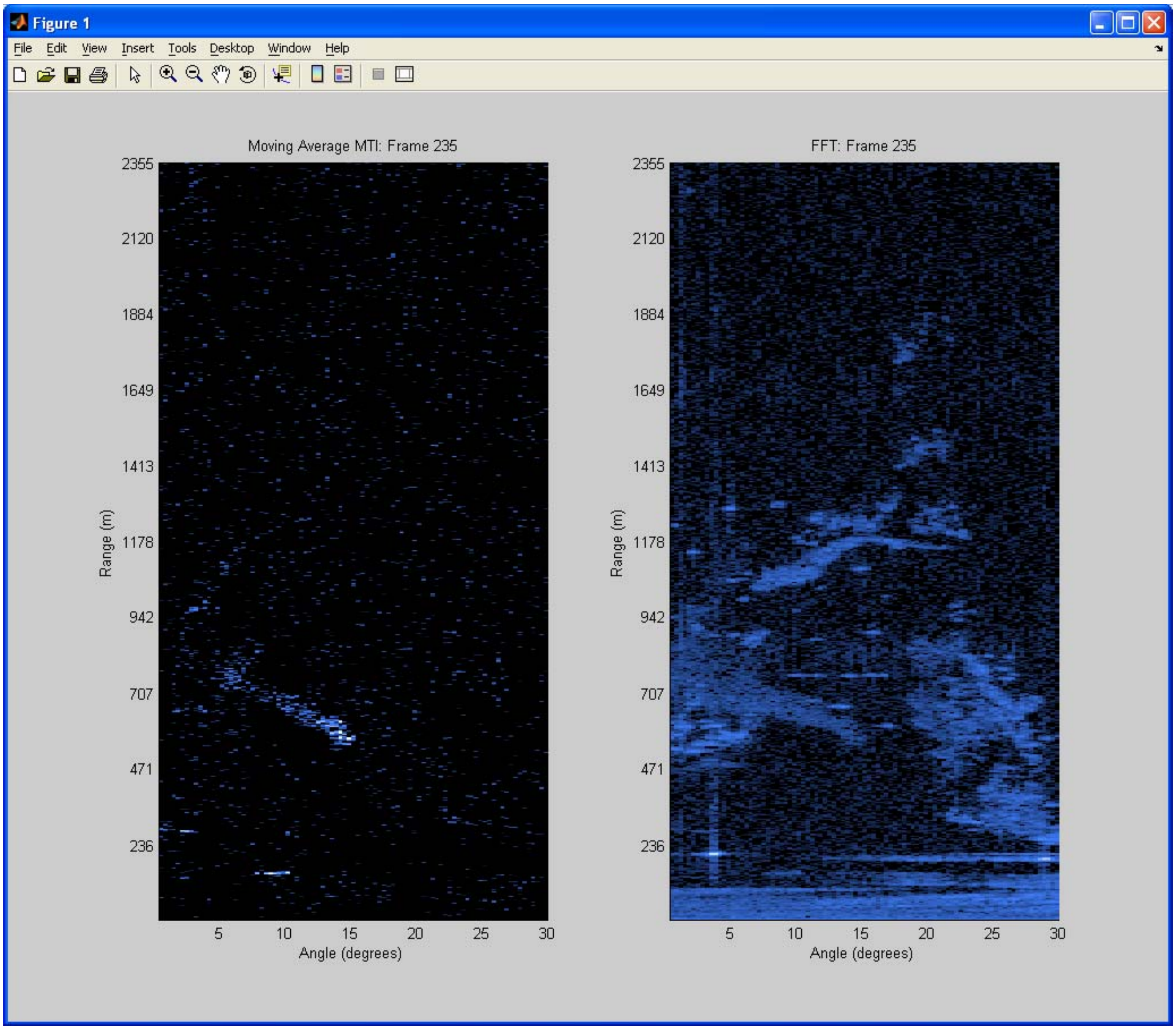

FIGURE 4-6. LEFT: MTI WITH N=10. RIGHT: RADAR IMAGE OF THE FLOCK FLYING OVER TRIGG LAKE.

In Figure 4.7, N was increased to 100 and shows a good representation of how the MTI performs. The flock of birds is very evident to even the untrained eye in this example and the noise level has been reduced even further. Although N=1, N=10, and N=100 were demonstrated in this analysis, the exact size of the moving average for the MTI will remain up to the user and depend upon system requirements and restrictions.

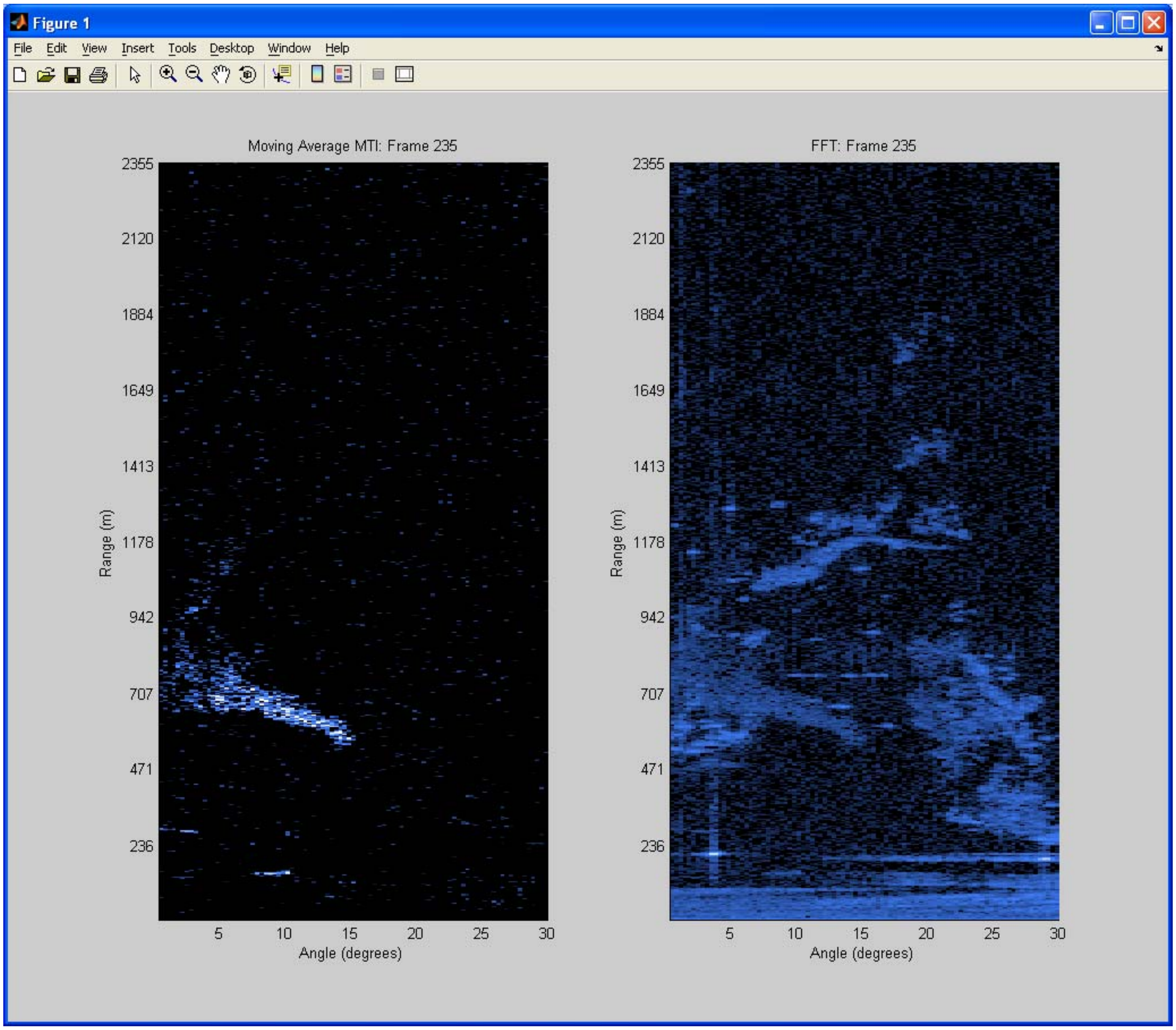

FIGURE 4-7. LEFT: MTI WITH N=100. RIGHT: RADAR IMAGE OF THE FLOCK FLYING OVER TRIGG LAKE.

4.2.2 Cell Averaging Filter

A cell averaging filter acts as a low pass filter for the image created by the post processor. The purpose of using this type of filter was to remove some of the fluctuations in the noise and also in the flock of birds. The goal was to reduce the visible noise and make the flock look uniform. The filter moves cell by cell throughout the entire matrix of values and replaces each value with the average of the cells around it as illustrated in Figure 4.8. The center cell was included in the average and can have the same weight as the cells around it or a greater weight as shown in equations 1 and 2 respectively. The cell averaging filter described in equation 2 was used before the moving average filter and the output is shown in Figure 4.9. The flock of birds looks more uniform and the visible noise was reduced.

Equation 1

$$Cell_5 = \frac{Cell_1 + Cell_2 + \cdots + Cell_8 + Cell_9}{9}$$

Equation 2

$$Cell_5 = \frac{Cell_1 + \cdots + 3 \cdot Cell_5 + \cdots + Cell_9}{11}$$

Cell 1	Cell 2	Cell 3
Cell 4	Cell 5	Cell 6
Cell 7	Cell 8	Cell 9

FIGURE 4-8. CELL AVERAGING FILTER.

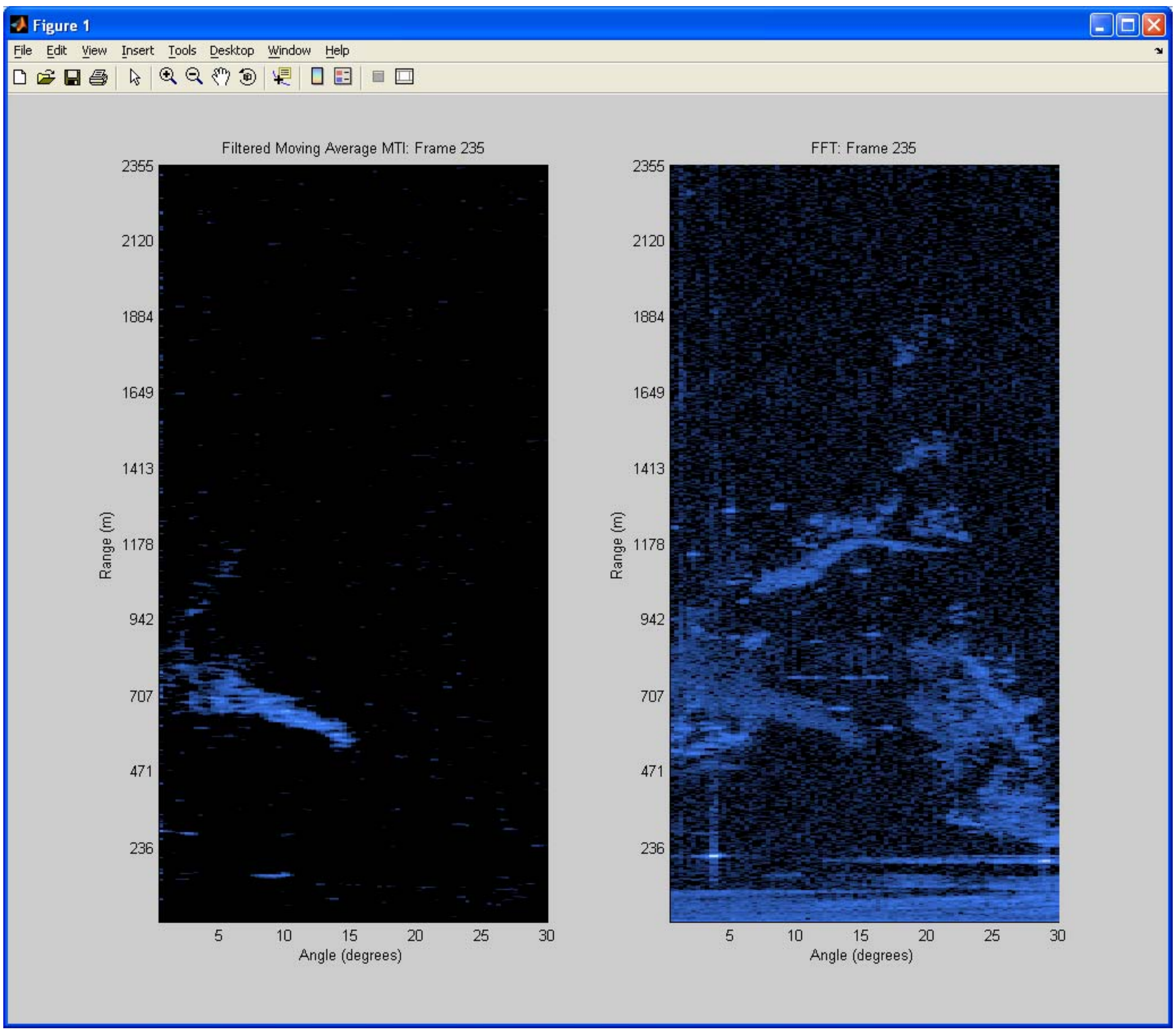

FIGURE 4-9. LEFT: CELL FILTERED USING EQUATION 2 WITH AN MTI SET AT N=100. RIGHT: RADAR IMAGE OF THE FLOCK FLYING OVER TRIGG LAKE.

4.3 RADAR RANGE FALLOFF EVALUATION

To verify basic radar performance, a range test was performed using a corner reflector set up at 500 meter increments down a taxiway such that it was inside the main beam of the radar. Using some estimation techniques, the change in magnitude of the returns from the corner reflectors at different distances can be compared to the expected change in magnitude due to range ($1/\text{range}^4$).

4.3.1 Radar Return Magnitude Estimation Techniques

In Figure 4.10, the 500 meter corner reflector is shown sitting on the taxiway in the right image. The left image shows a close up of the corner reflector returns measured by the radar.

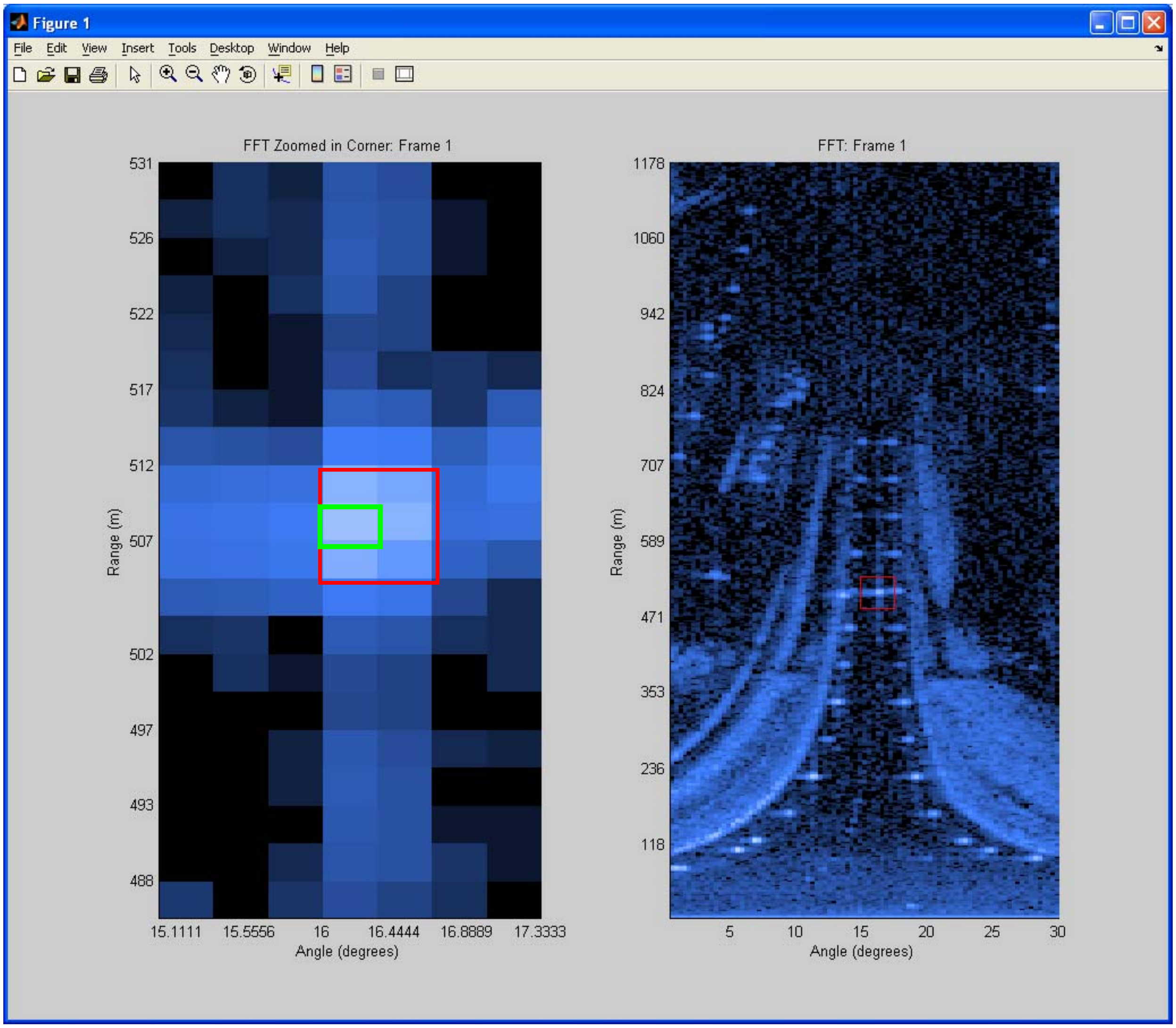

FIGURE 4-10. LEFT: ZOOM IN OF THE CORNER REFLECTOR AT 500 METERS. RIGHT: RADAR IMAGE OF THE CORNER REFLECTOR SITTING ON THE TAXIWAY AT 500 METERS.

The corner reflector returns are measured using multiple cells. Over time these cells can shift in angle because of wind movement, atmospheric effects, or measurement uncertainty. To account for multiple cell returns and shifting, an average over time was used to estimate the magnitude of the return from the corner reflector. In the average, all frames were sorted from highest to lowest based on the total magnitude of the return from the corner reflector. The total magnitude of the return was then found using two methods. The first method involved taking the average of a matrix of cells that measured the return. In the 500 meter case of Figure 4.10, the average was taken for the 2 by 3 matrix highlighted by the red box in the left image. In the second method, only one cell was used, as highlighted in Figure 4.10 by the green box.

After the total magnitude was found and the frames sorted, a percentage of the highest values was used for the final estimate of the magnitude of the return for the corner reflector. In other words, if only the top 5 percent of the values were used out of 100 frames, then the first five frames in the ordered list would be used for the final estimation. Table 4.1 shows the estimated magnitudes for all corner reflectors. A variance is included next to each estimated magnitude.

Recall that the radar hardware performed a sensitivity time control function to suppress the magnitude of near-in returns. If this filtering consisted of a perfect $1/R^4$ function, the corner reflector return would appear at the same magnitude regardless of range from the radar. However, Table 4.1 shows that the corner reflector magnitude does not remain perfectly constant with range. Therefore, Table 4.1 can provide amplitude correction as a function of range.

TABLE 4-1. ESTIMATED MAGNITUDE OF CORNER RETURNS ASSUMING $1/R^4$ STC IN HARDWARE. ALL ESTIMATED VALUES SHOWN ARE IN DB.

Corner Distance	**Average Top 5%**	**Variance**	**Average Top 25%**	**Variance**	**Average Top 50%**	**Variance**
500m (3 X 2 Matrix)	48.7	8.13	48.7	3.17	48.5	2.65
500m (Center Left Cell)	51.2	0.03	50.8	0.05	50.6	0.08
1000m (2 X 2 Matrix)	49.2	0.95	48.9	1.01	48.9	1.05
1000m (Top Left Cell)	50.9	0.05	50.7	0.02	50.6	0.02
1500m (2 X 1 Matrix)	51.3	0.09	51.2	0.09	51.1	0.14
1500m (Bottom Cell)	51.3	0.03	51.0	0.04	50.8	0.05
2000m (3 X 1 Matrix)	45.4	0.01	45.0	0.71	44.8	0.71
2000m (Center Cell)	46.4	0.004	46.1	0.06	45.9	0.07

4.3.2 Range Falloff Evaluation

In the given situation, the corner reflectors should produce large consistent returns. The values averaging only one cell and using the top 5 percent of the frames had the largest and most consistent (smallest variance) returns and, therefore, were selected for the remainder of the range analysis. Using the 500 meter test as a reference, the magnitude of the corner returns were calculated at their actual range. The expected magnitudes were also calculated. Table 4.2 shows the estimated and expected values and gives the actual distances from the radar to the corner reflector. Figure 4.11 shows the same results graphically. The data shows that the 1004 square meter corner reflector signal level closely matches the expected $1/R^4$ falloff to a range of about 1500 meters. At greater ranges the drop off in amplitude is greater than expected.

TABLE 4-2. ESTIMATED MAGNITUDE OF CORNER RETURNS. ALL ESTIMATED VALUES SHOWN ARE IN DB.

Corner Range	Estimated Measured Magnitude	Expected Magnitudes	Actual Range (m)
500m	51.7	51.7	51.7
1000m	39.4	40.1	39.4
1500m	32.8	33.2	32.8
2000m	22.9	28.2	22.9

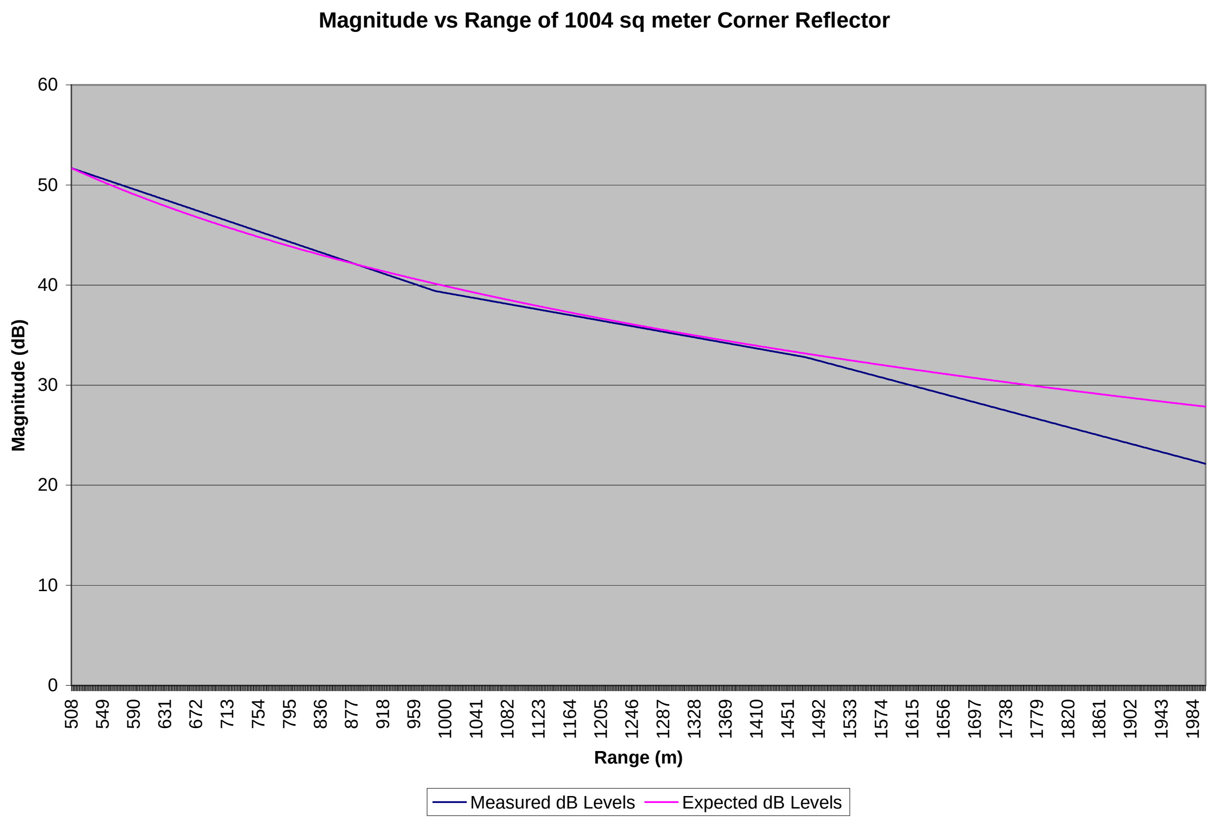

FIGURE 4-11. CHART OF THE ESTIMATED MAGNITUDE OF THE CORNER RETURNS COMPARED TO THE EXPECTED MAGNITUDES.

4.4 SIGNAL TO NOISE RATIO ESTIMATIONS

There is an ongoing effort to calculate the radar cross section (RCS) of different types of birds both alone and in flocks. For this calculation to be accurate the calibration of the radar and the effects of the hardware filter must be known. In addition, a target with a known RCS (corner reflector) must be placed in the main beam of the radar and the returns measured in the same test such that no adjustments are made to the radar settings. Some of these requirements, in particular the final requirement, are unknown or unavailable for the DFW tests. This prevents a meaningful calculation of the bird RCS. The signal to noise ratio (SNR), however, does not have these same requirements. In an SNR calculation, the calibration factors for the signal and for the noise are the same and a meaningful ratio is produced. To measure the performance of the radar and estimate a maximum detectable range, an analysis of the SNR of a flock of grackles was performed.

The area for the SNR calculation was selected to meet two criteria. First, the majority of the flock must fly through the area to generate a good signal estimate of the flock. Second, the area must be void of clutter such that the noise estimate contains only noise and is not corrupted by clutter. The red box on the right side of Figure 4.12 shows the area selected for this SNR analysis. The left side shows a closer look at the area and the absence of clutter.

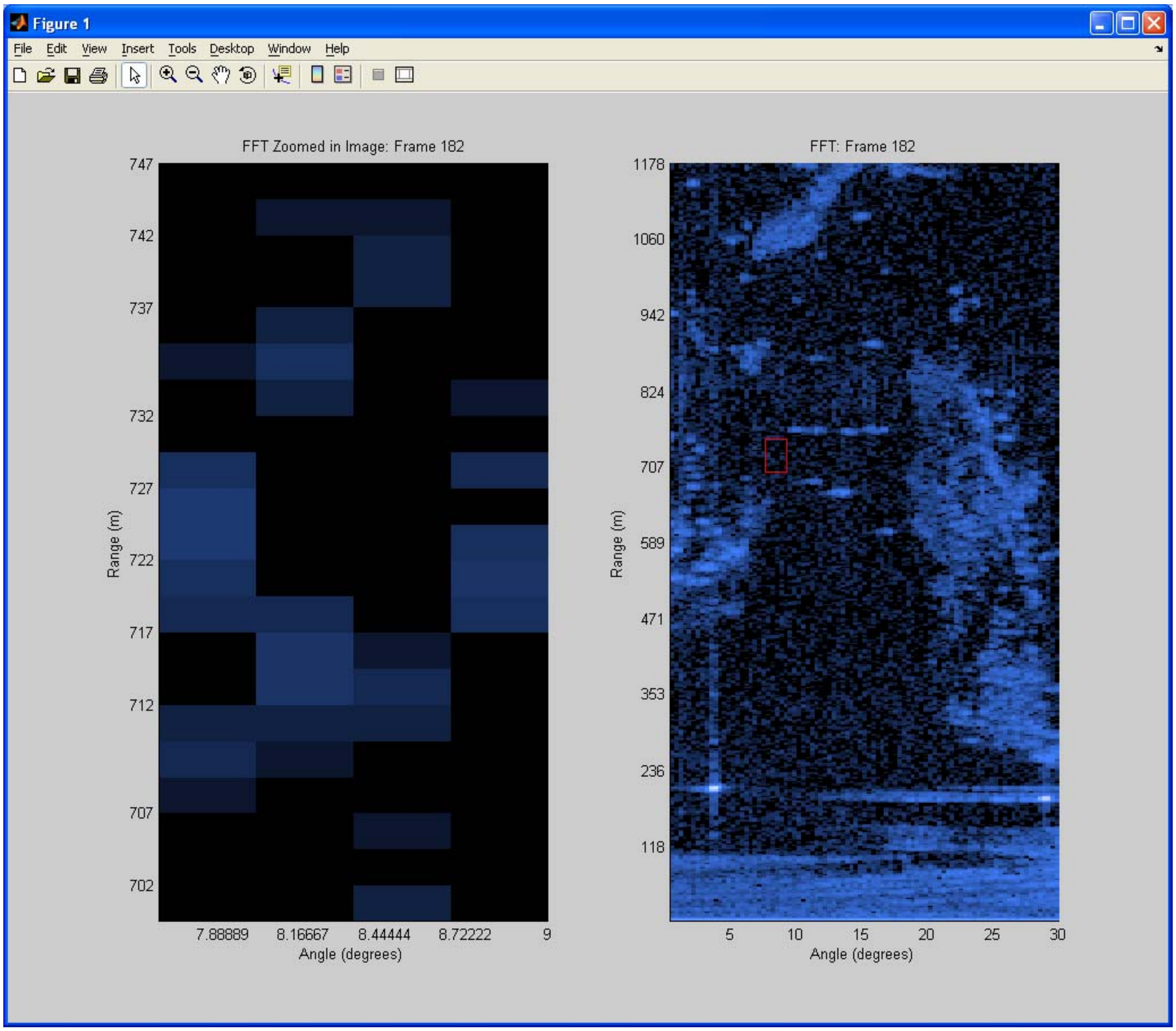

FIGURE 4-12. LEFT: ZOOM IN OF THE AREA USED FOR SNR CALCULATION. RIGHT: ORIGINAL FFT RADAR IMAGE OF THE TRIGG LAKE AREA.

4.4.1 Grackle Flock Signal Strength Estimation

Many of the same methods used for estimating the corner reflector radar return magnitudes were used for estimating the grackle flock signal strength. These methods include using the top percentage of values and selecting a matrix or a single cell over many frames. One additional technique considered the top percentage of values from a matrix in only one frame. In other words, the average was calculated only over space and not over time. The results of these estimations are show in Table 4.3.

TABLE 4-3. ESTIMATED GRACKLE FLOCK SIGNAL STRENGTH. ALL ESTIMATED VALUES SHOWN ARE IN DB.

Grackle Flock Picture	Average Top 25%	Variance	Average Top 50%	Variance	Average Top 75%	Variance
Matrix – Many Frames	29.9	0.96	28.8	1.81	27.8	3.43
Matrix – One Frame	29.3	0.53	28.4	1.31	27.4	3.12
One Cell – Many Frames	28.2	0.64	27.3	1.19	26.5	2.29

Estimates of grackle signal strength were computed for the top 25, 50, and 75 percent of cells. All cells were not used because the flock is not homogenous in space. As the flock flies, some areas inside the flock are sparsely populated, and these areas are not included in the estimation of the grackle signal strength. Because the signal strength should be representative of the entire flock, and not just one portion or one time instance, the estimation of SNR is made using a matrix of cells over many frames. The top 25 percent of the cells contains only the strongest returns representing the densest regions of the flock. The top 75 percent of values also contains less dense areas, and is considered to provide a better estimate of the entire flock.

4.4.2 Noise Level Estimation

To estimate the noise level, the same techniques used in the estimation of the grackle flock signal strength were used except that the minimum values were used instead of the maximum values. The minimum values were chosen because the noise level estimation should represent the magnitude of the returns the radar receives when no target is present. Table 4.4 shows the results of the noise level estimations using the minimum values.

TABLE 4-4. ESTIMATED NOISE LEVEL USING THE MINIMUM VALUES. ALL ESTIMATED VALUES SHOWN ARE IN DB.

Noise Picture	Average Min 50%	Variance	Average Min 75%	Variance	Average of 100%	Variance
Matrix - Many Frames	16.2	5.13	17.3	5.86	18.3	7.53
Matrix - One Frame	16.5	5.62	17.7	6.36	18.6	7.52
One Cell - Many Frames	16.6	4.99	17.5	5.33	18.3	6.02

The estimation of the noise level should include all radar returns with no targets or clutter present. From the visual data logs taken for this test, no substantial targets were observed in the selected area during the frames used for the noise estimation. However, a few birds or other small targets might have moved through the area without detection by spotters or the radar (only designed to see flocks at that range). Therefore, the average using the minimum 75 percent of the values of the matrix over many frames is used for the SNR analysis. The matrix over many frames provides the best possible average of the noise over time. Furthermore, to ensure the accuracy of the SNR, the identical space must be used for the signal and noise estimations.

4.4.3 Signal-to-Noise Calculation and Predicted Detection Range

A signal-to-noise ratio is given by target received power divided by average noise. Using the 75 percent values for the matrix with many frames, chosen in sections 4.4.1 and 4.4.2, an SNR value of 10.45 dB results. This SNR was calculated for a target at a range of 722 meters. Using the following equation, we can parametrically calculate the estimated range the radar can detect a flock of grackles based on the SNR needed by the post processing algorithms. The results are shown in Table 4.5.

$$(required\_SNR) - (given\_SNR) = 40 \cdot \log_{10}\left(\frac{722}{predicted\_range}\right)$$

TABLE 4-5. ESTIMATED DETECTION RANGE FOR A FLOCK OF GRACKLES DEPENDING ON THE REQUIRED SNR.

Estimated Ranges for Detection of a Flock of Grackles					
Required SNR	20 dB	15 dB	10 dB	5 dB	0 dB
Predicted Range (m)	417	556	741	988	1318

The results in table 4.5 follow closely with actual detection ranges seen by the radar for a flock of birds the size of grackles. A required SNR of 0 dB indicates that the target and noise levels are the same, and that a human operator can distinguish legitimate targets by observing patterns over time. This is a highly optimistic assumption which is generally not achievable in practice. However, the required SNR of 0 dB provides an upper bound on performance. Automatic detection algorithms (no human intervention) generally require 10 to 20 dB SNR, depending on the acceptable false alarm rate. False alarm rates have not been considered in this analysis. The amount of automated processing and target recognition implemented will determine how much SNR will be needed for the final system.

4.5 FURTHER ANALYSIS

More work is needed to determine the RCS of specific bird types and to improve the signal processing algorithms. Improved target detection and false alarm control can be achieved by the implementation of a tracker and pattern recognition algorithms.

5. CONCLUSIONS

The BIRDAR™ radar hardware and support equipment performed well during the DFW field testing campaign. Operation of the radar was consistent and reliable. The support components including the trailer, associated equipment, and personnel functioned well. The protocols developed for this testing were determined to be sound, and provide a model for future testing. The data collection procedures were consistent, and good quality data was obtained. Although still under development, analysis procedures (Appendix A) have provided useful information about radar performance. The availability of raw data from the radar system will support future analysis and methods development.

Based on the data collected during the DFW test campaign period, the effective range for specific bird activities has been determined. The first type of birds studied is blackbirds, mainly consisting of common grackles (weighing 115 g on average) and European starlings (80 g). Blackbird flocks were detected at up to 1,300 m, but at extreme ranges the signal was visible only if the operator was aware of the presence and general location of a target, and post-processing techniques were optimized for image enhancement. The upper effective detection range for flocks of blackbirds was 1,200 m, with 1,000 m being the upper detection limit at which bird flocks were consistently detectable using MTI processed images.

Raptor detection varied with the mass of the species, for example, the American kestrel mass averages 115 g, while hawks and vultures mass averages 1-1.5 kg. For these larger birds, which are the greater concern for flight safety, the upper detection range was 1,200 m. The detection limit for kestrels has not been determined, but is believed to be less than 500 m (based on the absence of radar detection for a confirmed sighting at 500 m).

In this test campaign, hawks and vultures were the largest birds present. Airport wildlife records indicate cormorants (1.8 kg) were present on site at the time of testing. Detection #13 may have been cormorants but independent observations at the time of radar testing for this detection are unavailable, so the use of this detection in radar evaluation will be limited. In addition to cormorants, other bird species regularly occur at DFW, such as Canada geese, which can weigh up to 6.6 kg. These large bird species were not present during the test campaign but it is likely that they would have been detected at the ranges confirmed, with likely detection of flocks at up to 2.3 km based on other testing of the radar (Appendix B).

As part of the radar development, the radar was tested with bird targets on several other occasions. A summary of this additional testing is provided in Appendix B. For these trials, the emphasis was placed on radar system evaluation rather than bird detection following the test protocol used at DFW. In these trials, ground truthing of detections was limited or absent. Furthermore, hardware development occurred between these trials, which makes direct comparison with DFW results more complicated. However, the results of these trials are still valuable in bird detection analysis and should represent minimum detection capabilities that can be verified when future test campaigns include large mass bird species.

The Klamath testing detected a large flock of snow geese at 2.1 km, and many birds at closer range. The results from the Salton Sea demonstrated that individual pelicans were consistently visible at up to 1.6 km, and post-processing revealed individual bird signals at 2 km. While there is no record of the farthest flock detected in the field, post-processing detected flocks of large birds such as geese as far away as 2.3 km (plus a very weak signal at 2.6 km from a flock of 100 snow geese).

In a supplemental analysis, the Air Force Research Laboratory applied several moving target indicator (MTI) methods to the data. A moving average filter was incorporated to reduce the visibility of clutter, and a cell averaging filter was added to flatten spikes in the noise and lower the number of false alarms. The analysis focused on two tests conducted as part of the DFW campaign. One test was conducted on September 22 to determine the detection range of BIRDAR™. In this test BIRDAR™ was oriented down a taxiway. The radar performance closely matched the expected performance of the radar at ranges up to 1,500 meters where detection began to degrade slightly. The second test used in the analysis was conducted at Trigg Lake, on September 15, 2004 from 7:09 a.m. to 7:15 a.m. A large flock of grackles, approximately 1,000, flew over Trigg Lake and was detected by the radar (Detection # 12, Section 3, Page 7). The flock detected in this test was used for MTI processing developments and grackle radar cross section calculations. Signal-to-noise ratio (SNR) calculations were also performed on this data. The results of these analyses gave an upper limit for the detection range with a required SNR of 0 dB. With a human operator to distinguish legitimate targets, the range predicted closely follows the observed detection ranges seen by the radar for a flock of birds the size of grackles. Automatic detection generally requires 10 or more dB SNR. The larger SNR requirement will significantly reduce the detection range of the radar.

APPENDIX A – ILLUSTRATED VERSION OF SECTION 3.2

This appendix provides screen captures that further illustrate the analysis procedure that was described in section 3.2. The full text is repeated as well for clarity. All pictures are taken from a single detection (#14), which was an unidentified flock at 1.5 km (Figure A-1).

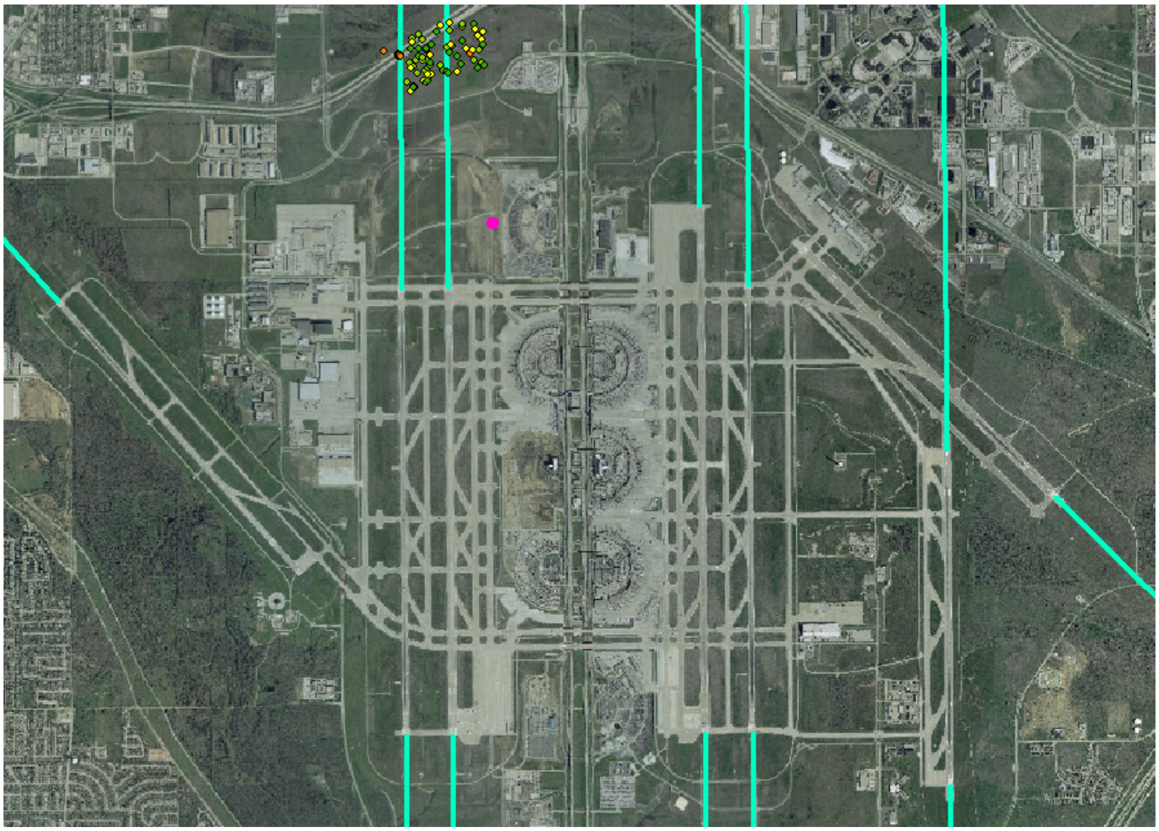

FIGURE A-1. OVERVIEW OF RADAR LOCATION (PINK) FOR DETECTION #14. APPROACH PATHS ARE SHOWN IN LIGHT BLUE, AND SOME OF THE RADAR RETURNS ARE SHOWN AS RED, YELLOW, AND GREEN DOTS.

Detection:
A bird signal was first identified by reviewing the radar data in the post processor at high speed (Figure A-2). The high speed made it more efficient to look for birds, and noise became less apparent relative to detections. Once a signal was identified, if it was weak, it was viewed several times to be sure that it was a positive detection rather than noise. When the signal was confirmed, the file name, frame number, and approximate distance to the signal were entered into a radar log in Excel. The type of signal (approximate size, flock type, and length of time it was visible) was logged as well.

Verification:
Once a signal had been found, it was viewed with the MTI (moving target indicator) mode to see if it is still readily viewable (Figure A-3).

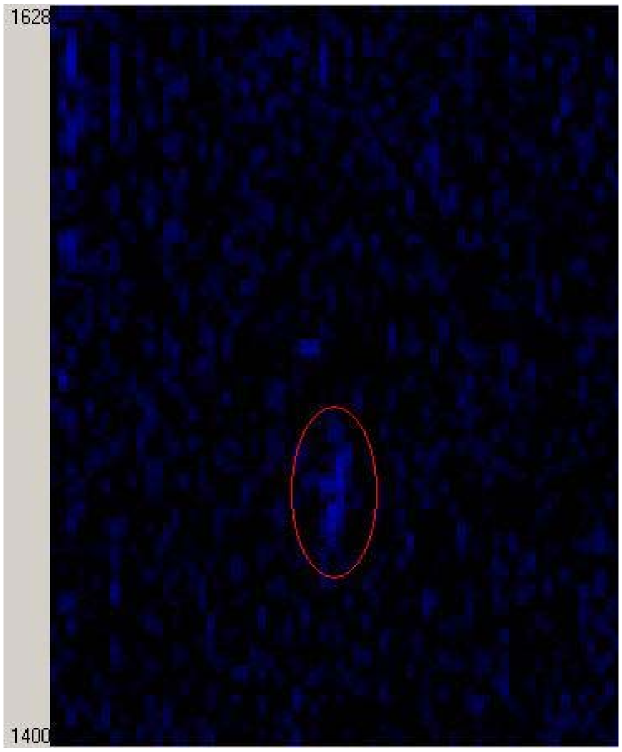

FIGURE A-2. A BIRD FLOCK SIGNAL AT 1.5 KM (CIRCLED IN RED).

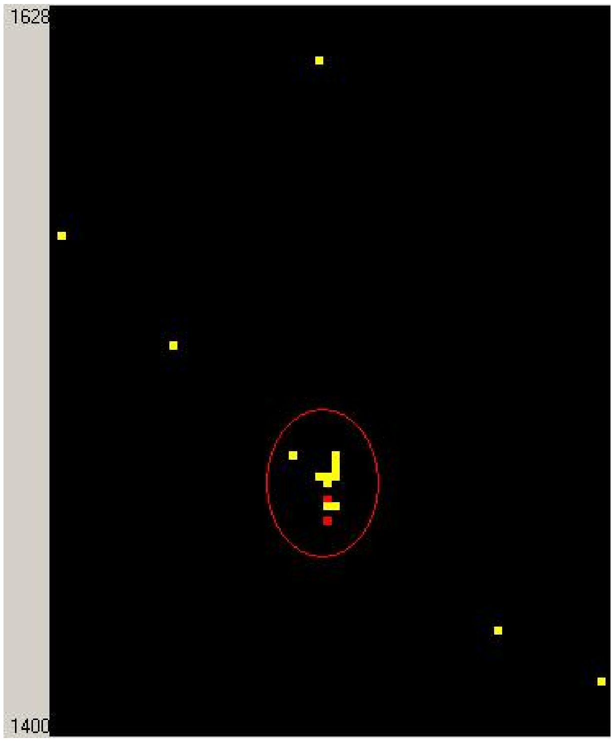

FIGURE A-3. THE SAME BIRD FLOCK SIGNAL, VIEWED WITH THE MTI AT A THRESHOLD OF 15 DB. THIS THRESHOLD WAS TOO HIGH; TOO MUCH SIGNAL WAS LOST.

This mode of the post processor filters out static unchanging background signals, and allows the moving detections to be isolated. It also allows data to be exported into tabular format, which is not possible in the raw data display.

The MTI settings used were static average, with a threshold of 15 dB. The threshold determines how strong the signal has to be; a high threshold filters out more noise, but also will cause some loss of the desired signal. For the weak signals that were not apparent at this level, the threshold was adjusted to a lower level (down to as low as 10 dB) to see if it was detectable at all in MTI mode, and if so, how much background noise was present (Figures A-4 and A-5).

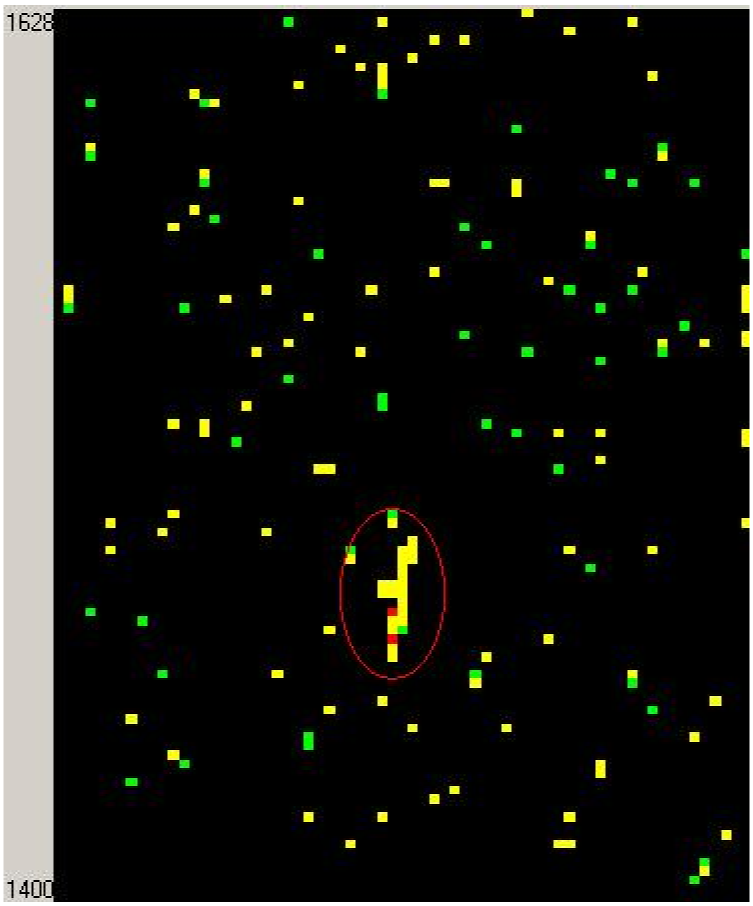

FIGURE A-4. THE SAME BIRD FLOCK SIGNAL, VIEWED WITH THE MTI AT A THRESHOLD OF 10 DB. THIS THRESHOLD WAS TOO LOW; THERE WAS TOO MUCH NOISE TO CLEARLY VIEW THE SIGNAL.

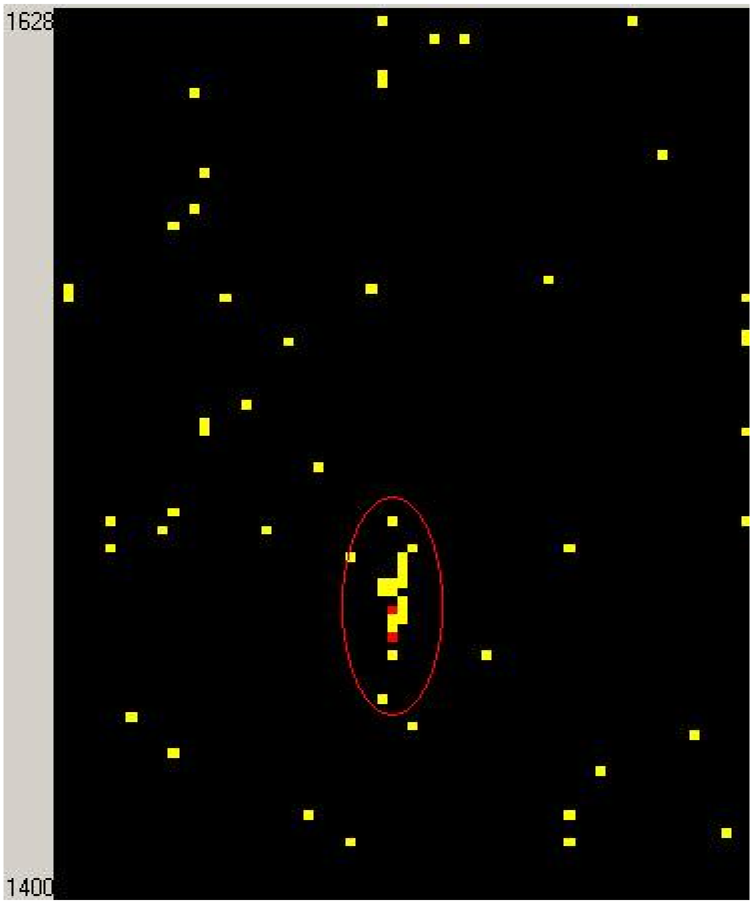

FIGURE A-5. THE SAME BIRD FLOCK SIGNAL, VIEWED WITH THE MTI AT A THRESHOLD OF 12 DB. THIS WAS THE INTERMEDIATE THRESHOLD VALUE CHOSEN FOR ANALYSIS.

If it is impossible (or practically impossible) to see the signal in MTI, the signal was logged as not viewable in MTI. If it was viewable, but only at a threshold under 15, it was logged as marginally viewable in MTI.

Identification:

To confirm the type and number of bird(s) detected, the first step was to figure out the time of signal. The starting time of the radar file will be correct, but time then progresses in the post processor at approximately twice the speed of real-time, so a rough estimate of actual time can be calculated. Once the time of the flock was determined, the paper logs, audio logs, and PDA logs were consulted to see what information (if any) was available about bird activity at that time. Since all watches and device clocks were synchronized, it was fairly straightforward to determine what information was available. Information about the bird detection, as well as what sources the information came from, was logged.

For detections where the sole purpose of analysis was to confirm that it was bird activity and to describe the detection in great detail, no further assessment was carried out.

Display:
Any flock of serious interest was exported through the MTI to a dbf file so that the data could be analyzed. The post-processor zoom feature was used to display the data in greater detail and to export only data in the zoomed window. This reduced file size and processing time. The dbf file was then imported into an Access database, and the following SQL query was used to transform the radial coordinates into Cartesian coordinates (sample values have been entered into the variable components of the query, and are in bold):
SELECT ID, MAGNITUDE, RANGE, AZIMUTH, FRAMECOUNT,
DateAdd('d',0,DateAdd('h',**7**,DateAdd('n',**18**,DateAdd('s',**56**+round(**0.821724***FRAMECOUNT,0),'**14** Sep, 2004')))) AS timedate,
(**682885.153**+RANGE*Sin((Azimuth+**161**+15)*3.141593/180)*Cos(**3.2***3.141593/180)) AS xcoord,
(**3637645.24**+RANGE*Cos((Azimuth+**161**+15)*3.141593/180)*Cos(**3.2***3.141593/180)) AS ycoord INTO **9c_0004t**
FROM **9c_0004**;

The modified dbf was used to create a GIS file that allowed both display and interactive measurement/analysis in a visual format (Figure A-6).

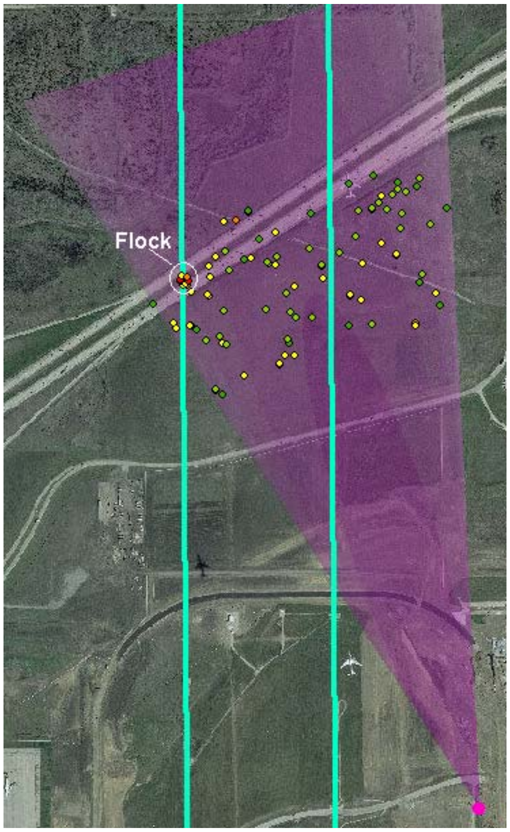

FIGURE A-6. ONE SECOND OF THE GIS DATA BEFORE FILTRATION. THE PURPLE CONE SHOWS RADAR FIELD OF VIEW, MOST OF THE YELLOW AND GREEN DOTS ARE NOISE.

For a full analysis, the non-flock returns (noise) were manually deleted from the MTI data, one second at a time in the GIS (Figure A-7). This is especially important for the display of weak signals that were exported with a low threshold value, or when the data needs to be in tabular format for analysis. The result is a dbf file with range, azimuth, magnitude, and time/date information for all flock returns.

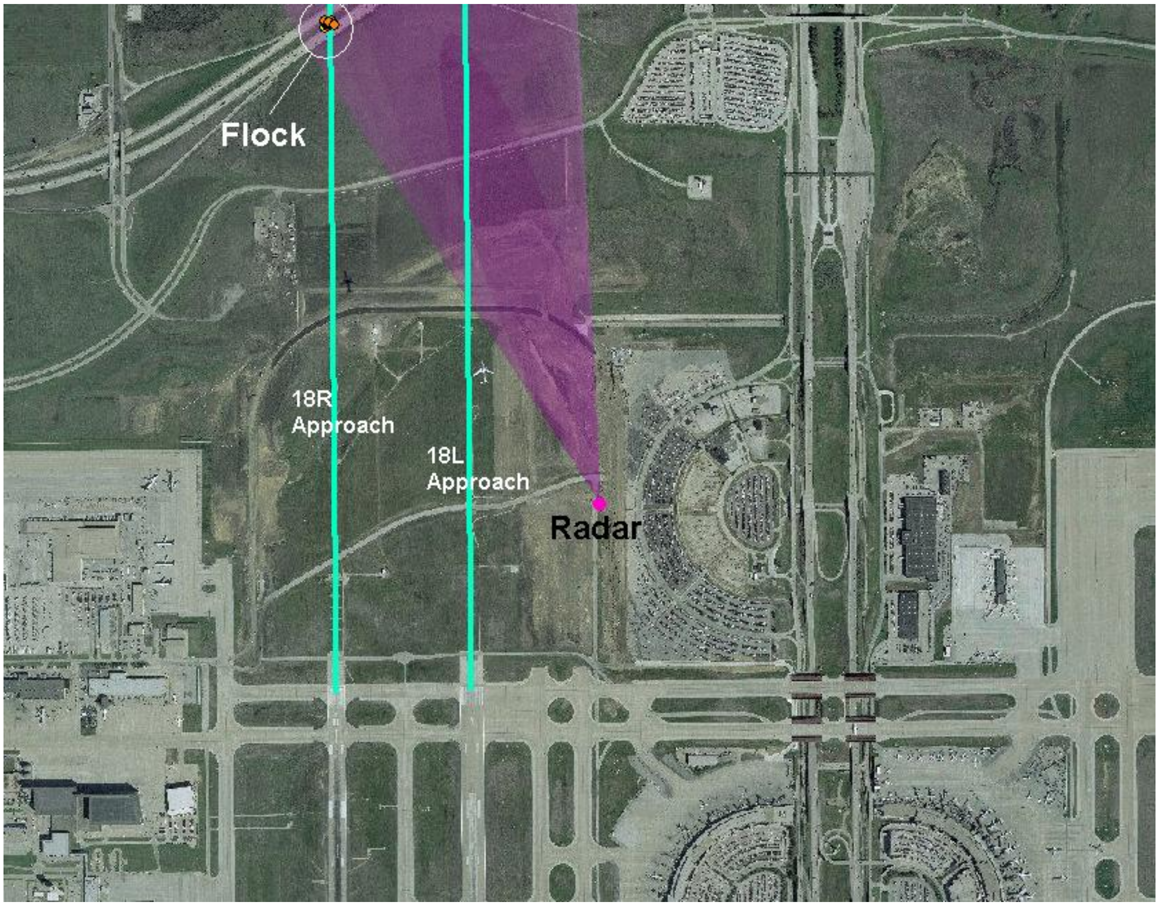

FIGURE A-7. THIS SHOWS ONE SECOND OF THE GIS DATA AFTER FILTRATION, AND ALSO SHOWS THAT THE DETECTED FLOCK MOVED THROUGH THE 18R APPROACH PATH, INDICATING A POTENTIAL HAZARD.

If the data was vertical (and the radar was fixed), display in GIS was much more complex. First, before filtering, the data was displayed as if it was horizontal (in a 30 degree horizontal cone) so that all of the data at different heights was distinct (Figure A-8), instead of layered into a 2.5 degree wide cone.

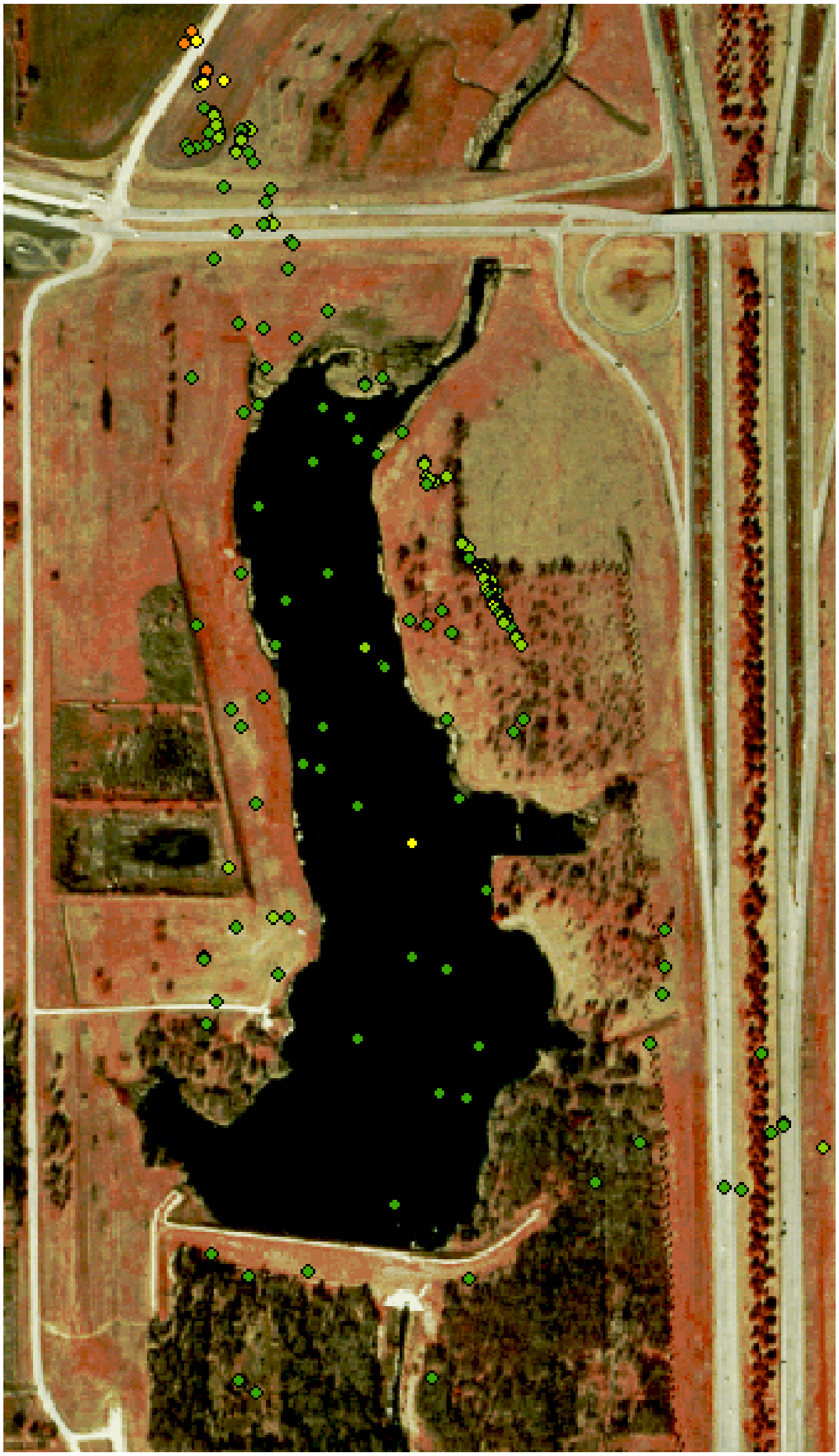

FIGURE A-8. THE VERTICAL RADAR DATA, ROTATED 90 DEGREES SO THAT INCREASING ELEVATION IS REPRESENTED BY POINTS BEING FURTHER TO THE RIGHT.

The data was manually filtered (Figure A-9), then transformed back into a 2.5 degree wide cone (Figure A-10). With the noise removed, the signal was visible, otherwise it was completely obscured (Figure A-11).

FIGURE A-9. THE VERTICAL RADAR DATA, ROTATED 90 AND FILTERED TO REMOVE NOISE.

FIGURE A-10.
THE DATA HAS BEEN TRANSFORMED BACK SO THAT THE POINTS ARE ACTUALLY IN THE CORRECT LOCATION. THE THREE SETS OF POINTS SHOW THE CENTER AND EDGES OF THE RADAR BEAM. THE COLOR SCHEME WAS CHANGED SO THAT DARKER REDS SHOW INCREASING ELEVATION.

FIGURE A-11.
THE SIGNAL IS OBSCURED BY THE NOISE, SINCE DATA AT DIFFERENT HEIGHTS IS BEING DISPLAYED TOGETHER. THIS FIGURE SHOWS THE NEED FOR FILTRATION.

The way this was achieved was to add coordinates to the data for the 2.5 degree cone centerline and edges. Height could then be shown with different colors if desired. If the data was recorded in vertical mode, but with the radar being manually moved back and forth to follow raptors, it is not meaningful to display the results in GIS, as no record was kept of precisely how the antenna was moved.

Measurement:
The next step was to pinpoint range information, i.e., the maximum range at which the flock was visible, the size of the flock, and the mean range variations over time. This information was used to determine how a single flock's signal changes, both from natural fluctuations and from moving farther away. This was accomplished by analyzing the raw data using the post processor, and recording minimum and maximum visible range of the flock every few frames (by clicking on the pixels at the near and far edges in the post processor, which displayed the range) (Figure A-12).

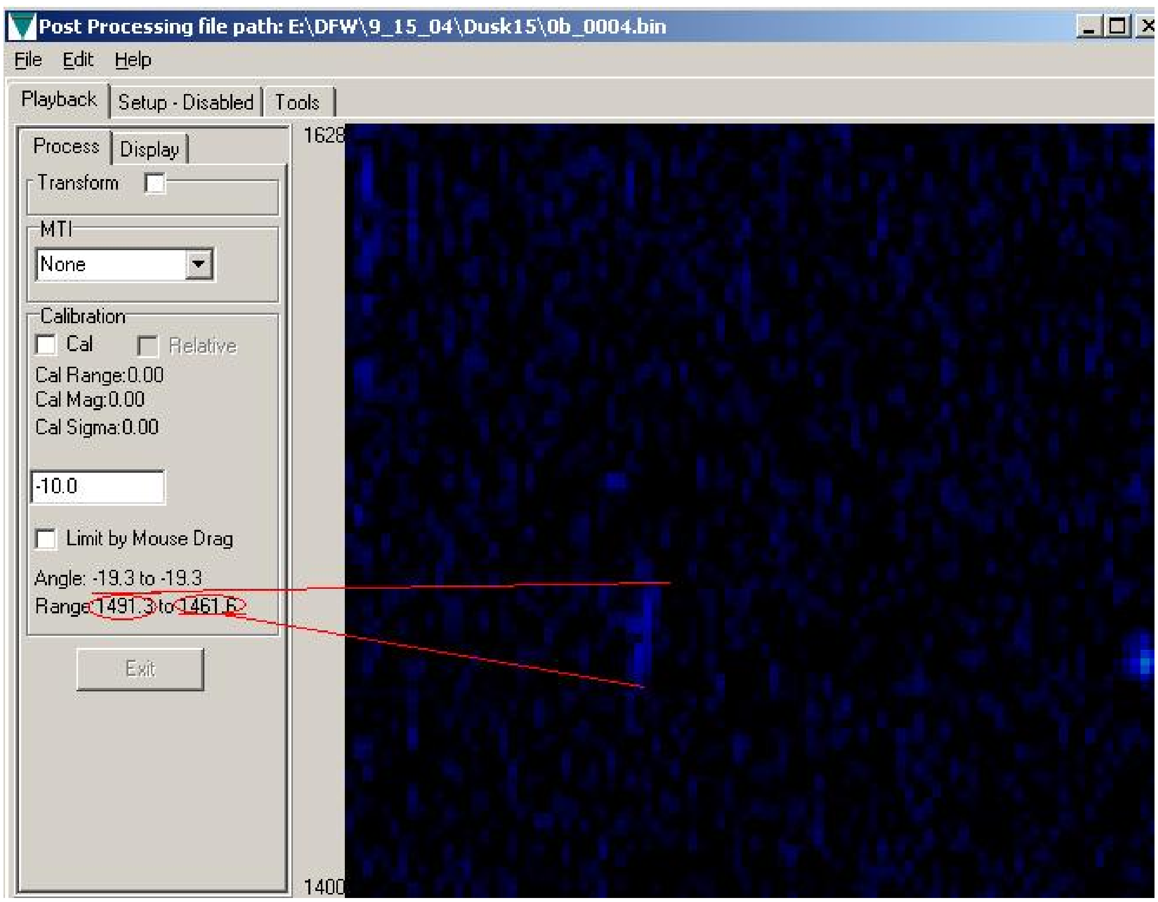

FIGURE A-12. THE RED LINES SHOW THE EXTENT OF THE FLOCK, THE CIRCLED VALUES ARE THE RANGES OF THOSE LOCATIONS AS MEASURED BY THE POST-PROCESSOR.

In this fashion, the distance and size of the flock were recorded over time. The elevation of the flock at each point was calculated from range and the known elevation angle of the radar beam.

Analysis:

The final step for selected returns was to examine the isolated dbf file containing only bird returns. This made it possible to start to see how much natural variation there was from second to second in the radar returns at a constant distance, and how much change in signal strength and pattern was evident as the mean range of the flock changed.

The raw radar data measurements of flock distance from the measurement section were plotted on a graph (minimum, maximum, and mean distance from the radar) to provide an indication of how the flock is moving and how the detected size of the flock changes over time (Figure A-13).

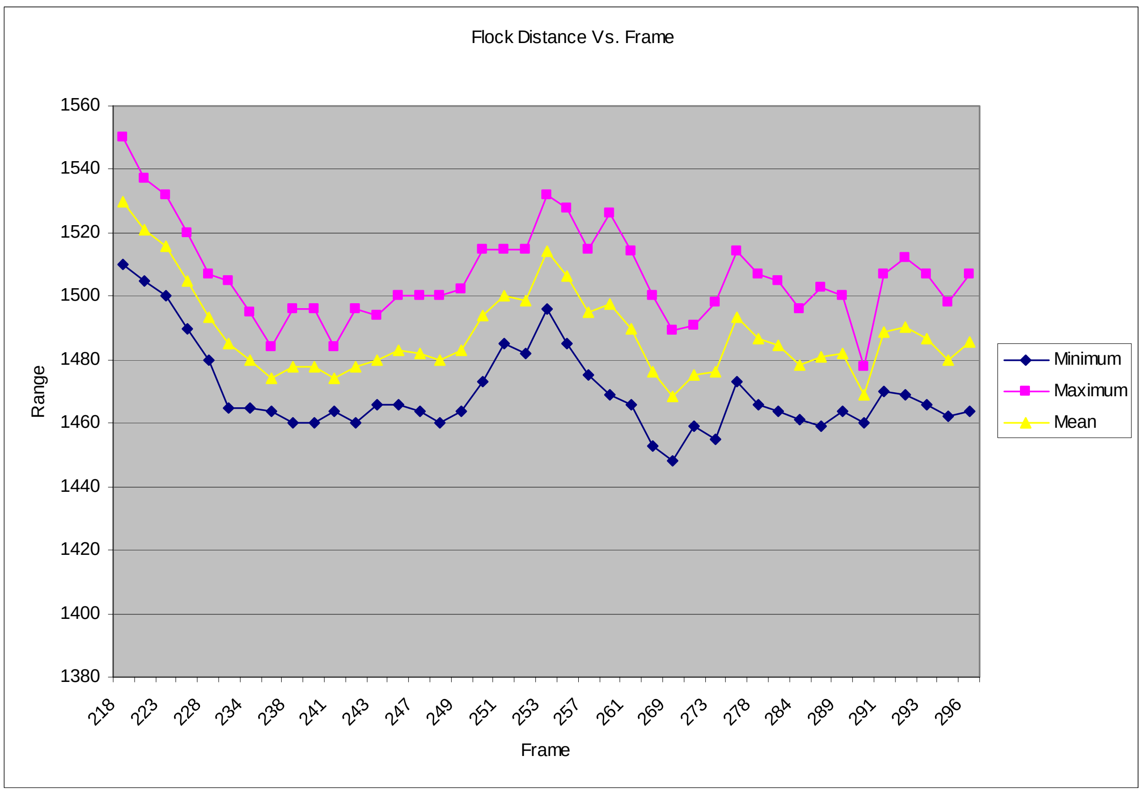

FIGURE A-13. THE FLOCK'S MINIMUM, MAXIMUM, AND MEAN DISTANCE FROM THE RADAR, OVER TIME.

Another graph of flock size over time was plotted to indicate how much variability was present in the returns (Figure A-14).

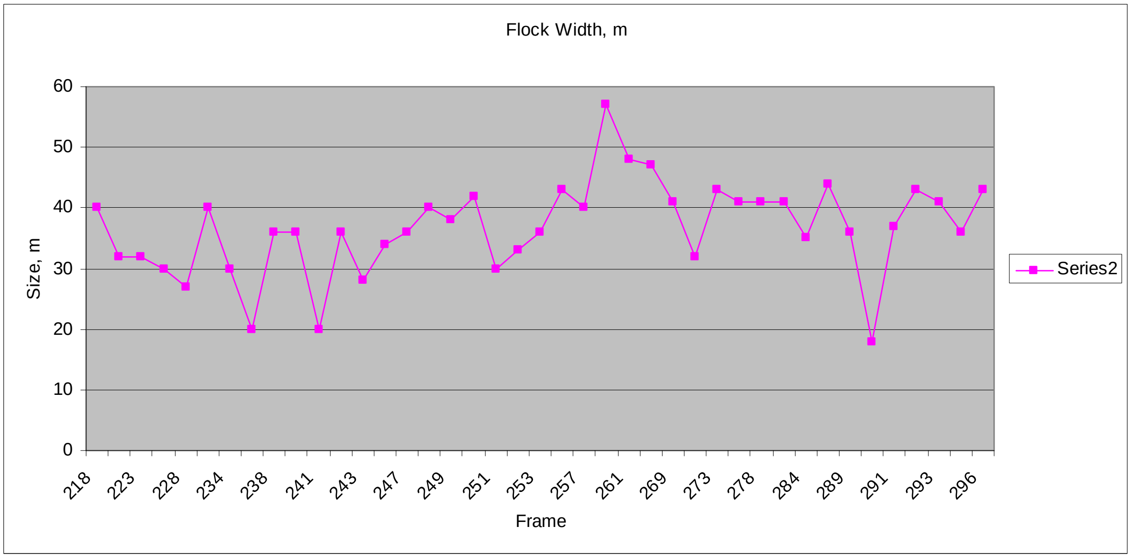

FIGURE A-14. FLOCK WIDTH OVER TIME.

For most signals, the birds were traveling perpendicular to the beam, so the 'size' being measured was actually flock width. To pinpoint where the flock was in 3-D, the minimum, maximum, and mean elevation of the radar beam was calculated for the mean range of each flock measurement. The volume of a radar cell at the mean range of each flock measurement was calculated as well. If the flock moved through a runway approach path, a plane's expected elevation on approach at the relevant area was determined. For detection 14, when the flock was at the location shown in Figure A-7, a plane on approach would be at 94 m AGL, while the flock was between 45 m and 111 m AGL.

To look for patterns in how signal strength changes over distance and time, graphs were created showing magnitude vs. distance (Figure A-15) and magnitude vs. time (frame number) (Figure A-16).

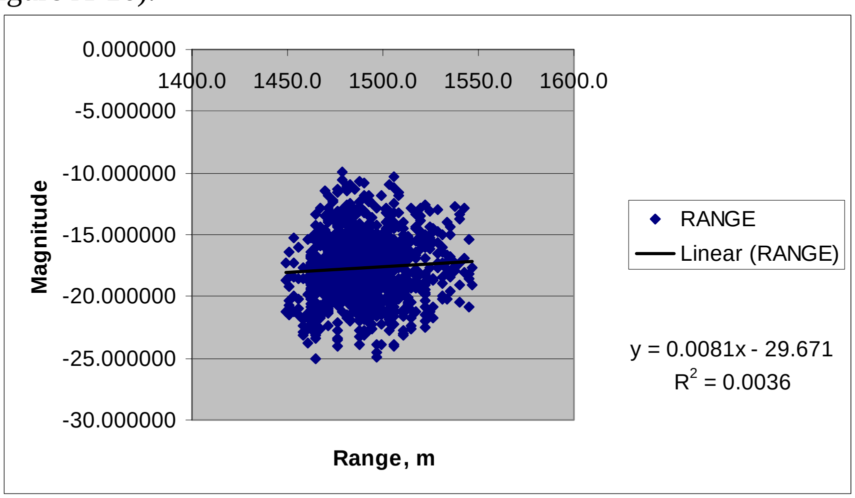

FIGURE A-15. THE MAGNITUDE DISTRIBUTION OF BIRD RETURNS BY RANGE. THERE IS NO CORRELATION BETWEEN THE TWO.

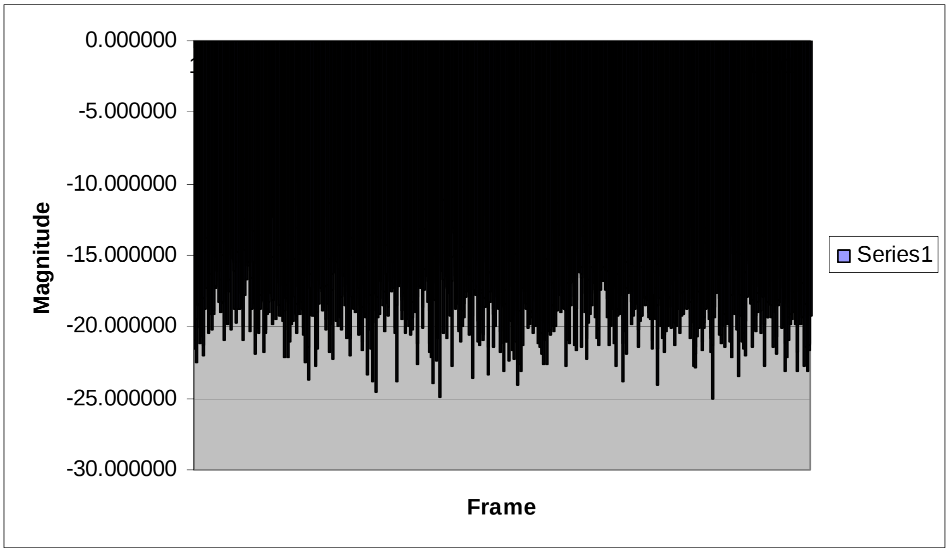

FIGURE A-16. MAGNITUDE AS IT VARIES OVER TIME. NO OBVIOUS PATTERN IS DISCERNABLE.

To try to reduce natural variation, the data were also analyzed by second (combining several frames of data); number of returns vs. time (Figure A-17), mean magnitude (by second) vs. time (Figure A-18) and sum magnitude (by second) vs. time (Figure A-19) are plotted.

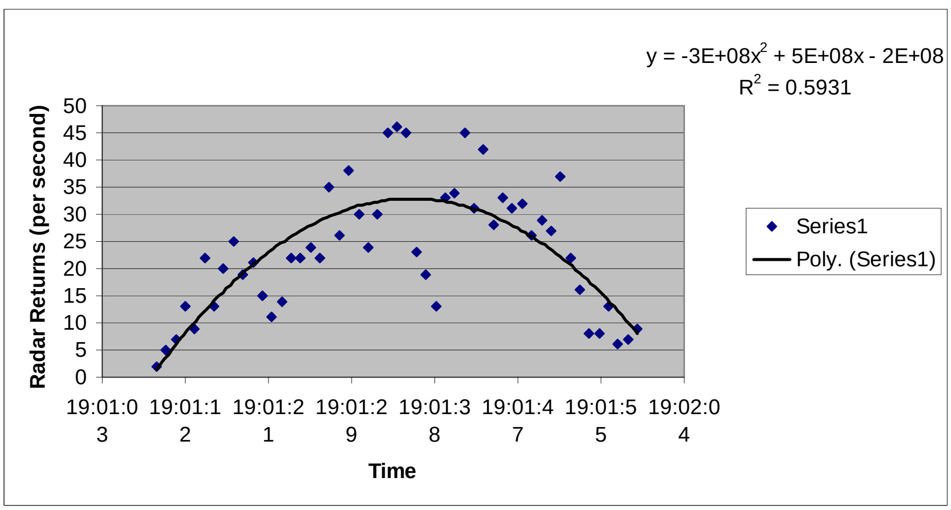

FIGURE A-17. THE NUMBER OF RADAR RETURNS FOR THE FLOCK OVER TIME. A LOOSE CORRELATION IS SHOWN, BUT THE NUMBER OF RETURNS IS NOT CORRELATED AT ALL WITH DISTANCE FROM THE RADAR.

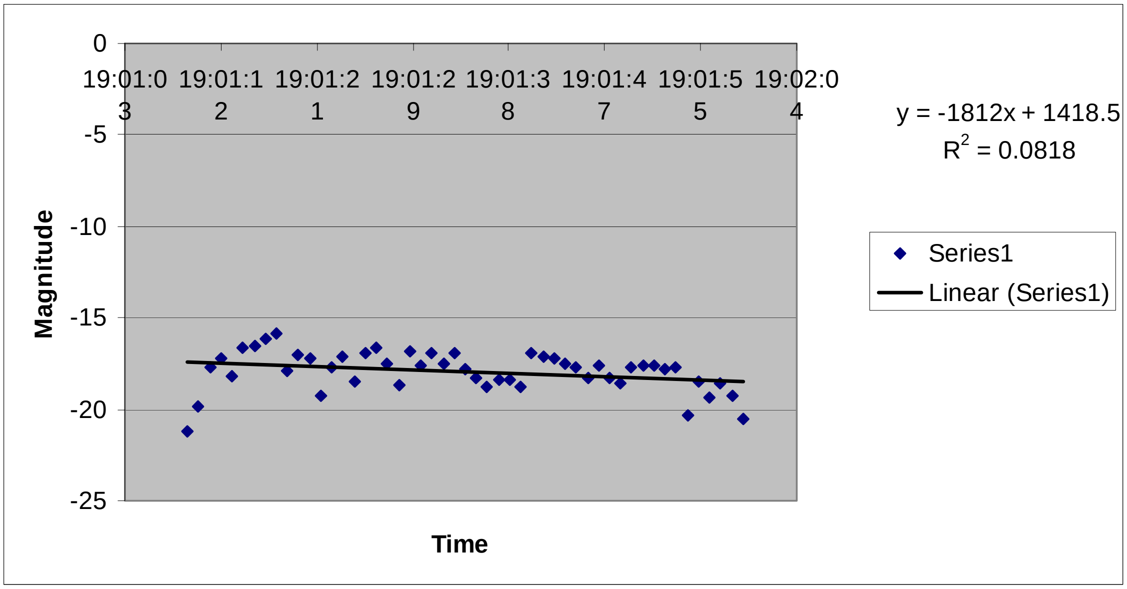

FIGURE A-18. MEAN MAGNITUDE (BY SECOND) VS. TIME. THERE IS NO CORRELATION.

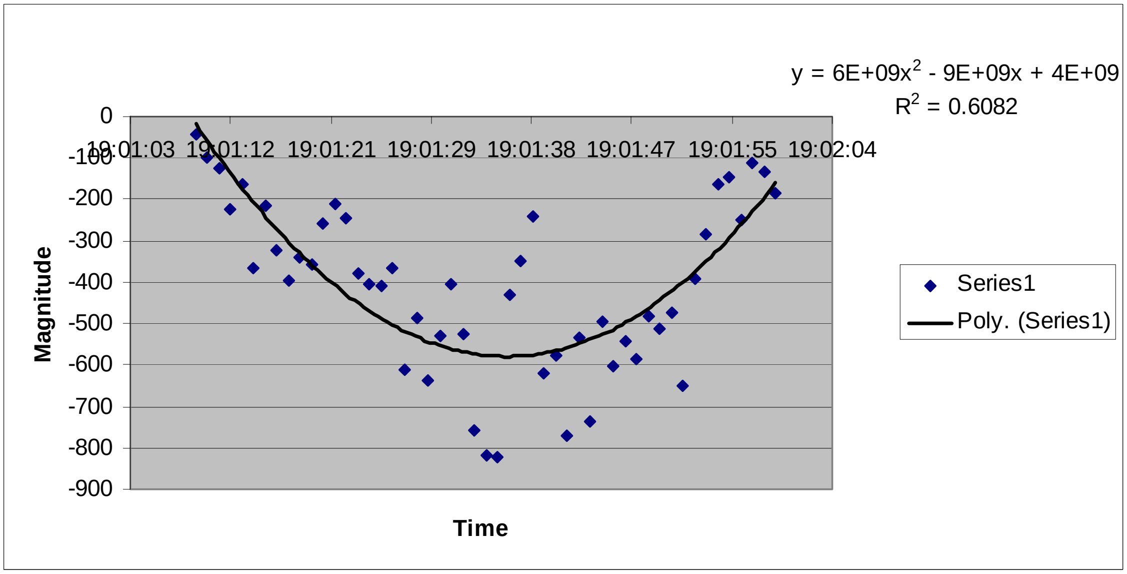

FIGURE A-19. SUM OF MAGNITUDE (BY SECOND) VS. TIME. A LOOSE CORRELATION IS SHOWN.

The magnitude distribution was plotted to determine typical amplitude and range values for the flock (Figure A-20).

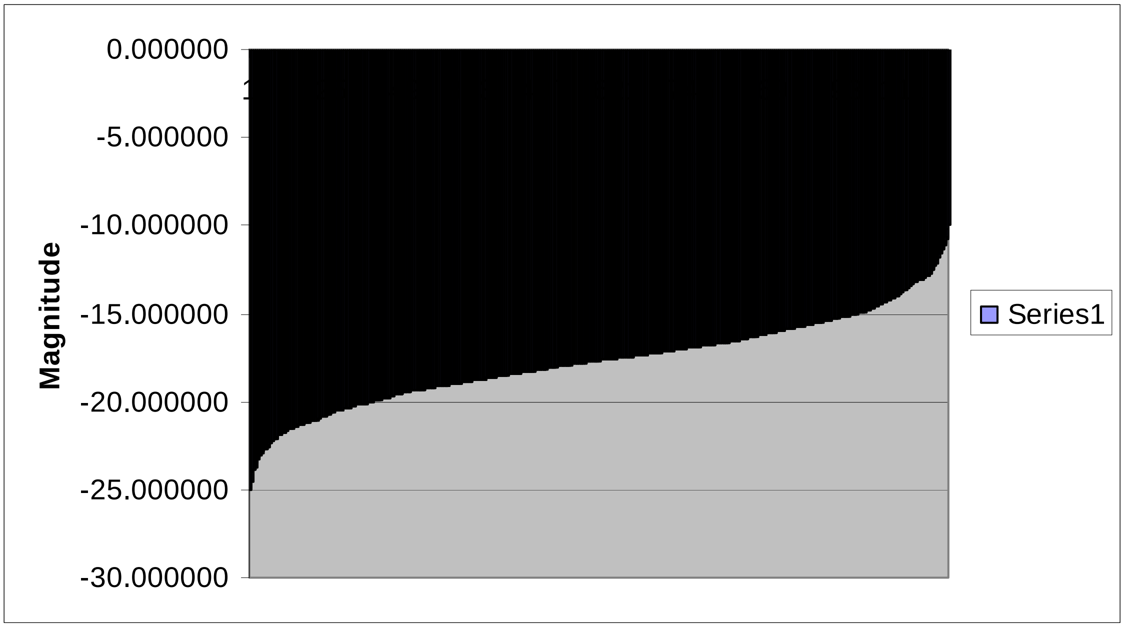

FIGURE A-20. MAGNITUDE DISTRIBUTION.

APPENDIX B – FIELD TESTING PRIOR TO DALLAS/FORT WORTH AIRPORT

B.1 Overview

As development of the radar progressed, it was tested at several intermediate stages with wildlife targets. The tests to determine the capability of the radar to detect birds were short duration (a few hours), and were an integral part of radar systems evaluation. A number of tests were carried out at Bolsa Chica Wetlands in Huntington Beach, CA. This location was selected based on its proximity to WaveBand's facilities in Irvine, CA, and because it consistently has wildlife (mostly small and medium sized birds). The results of these tests varied widely and were dependent on the state of the technology development at the time of the trials, as well as the birds present. Interpretation of detection parameters is also hampered by limited recording of wildlife observations and the absence of downrange observers. The birds that were detected by the radar were usually single gulls and black skimmers. They were typically only seen up to 1 km due to topographical limitations.

However, recognizing the need for more thorough evaluation of the radar, two other detection trials were conducted. The first was in the Lower Klamath National Wildlife Refuge and Tule Lake National Wildlife Refuge on April 7 and 8, 2004. This location, on the border between California and Oregon, was chosen because large populations of waterfowl were common (such as flocks of thousands of snow geese, which typically weigh 2.6 kg).

The second trial was conducted at the Salton Sea in California on August 26 and 27, 2004. This test used the same radar hardware and support trailer that was used at DFW. The primary objective of these trials was to confirm the systems integration and operational stability of the radar prior to the DFW campaign. At the Salton Sea, the radar detected large numbers of large birds (such as snow geese and American white pelicans, which typically weigh 7 kg). Although downrange observations are unavailable for the Salton Sea trials, these data do provide useful information for estimating the radar's capabilities.

B.2 Klamath Test

For testing at the Klamath Basin, the radar hardware was operated without the support trailer or equipment. The radar was mounted in a sport utility vehicle with the antenna facing out the back and the display and controls accessible through the rear side doors (Figure B-1).

FIGURE B-1. THE EXPERIMENTAL SETUP AT THE KLAMATH BASIN.

Testing was conducted for two days from about 6 am to 8 pm, in an effort to capture virtually all potential bird movement, and took place at several different sites in the Klamath Basin (Figure B-2).

FIGURE B-2. THE TEST LOCATIONS IN THE KLAMATH BASIN.

An effort was made at the Klamath to collect ground truthing information to provide the needed verification of radar detections. However, it proved difficult for one person to create a written record, while simultaneously using binoculars for bird identification and checking the radar display to verify the detections. Furthermore, the video camera which was supposed to record continuously throughout the test experienced a technical failure and created images much too blurry to be of use. Nonetheless, while the wildlife record had flaws, several major detections were noted (Table B-1).

TABLE B-1. SOME MAJOR DETECTIONS AT THE KLAMATH TEST.

Detection ID	Site	Date	Time	Duration	Bird Species/Type	Number	Flock Type	Range, m	Orientation	Direction
1	300	4/7	6:58	17	Snow geese	25	linear	200-300	horizontal	northwest
2	300	4/7	6:59	22	Snow geese	50	wide linear	200-350	horizontal	northwest
3	302	4/7	15:14	135	Snow geese	2000	large dense	350-1050	horizontal	east
4	305	4/8	11:14	104	White-fronted geese	3000	large dense	1500-2100	horizontal	east
5	306	4/8	19:20	30	Snow geese	1000	large dense	600-750	horizontal	northwest

TABLE B-2. SOME MAJOR DETECTIONS AT THE SALTON SEA TEST.

Detection ID	Site	Date	Time	Duration	Bird Species/Type	Number	Flock Type	Range, m	Orientation	Direction
1	1	8/26	18:13	55	Pelican	2	n/a	1250-1600	horizontal	northeast
2	1	8/26	18:25	140	Pelican	1	n/a	1300-2050	horizontal	northeast
3	2	8/27	6:07	100	Unidentified flock		thick linear	1400-1700	horizontal	south
4	2	8/27	6:20	15	Pelican	1	n/a	2000	horizontal	north
5	2	8/27	6:31	25	Unidentified geese	100	2 small flocks	2450-2650	horizontal	west

As shown in Table B-1, there were large numbers of large birds observed at the Klamath. Birds were seen as far as 2.1 km away, and it appeared that the farthest detections did not represent the absolute upper limit of the radar.

B.3 Salton Sea Test

As mentioned above, the same support trailer was used at the Salton Sea and at DFW. (Figure B-3).

FIGURE B-3. THE RADAR SUPPORT TRAILER, SITED AT THE SALTON SEA (SITE 1).

Testing was conducted on and near the Red Hill Marina at the southeast corner of the Salton Sea (Figure B-4).

FIGURE B-4. TEST LOCATIONS AT THE SALTON SEA.

For the afternoon/evening of 8/26 and Friday morning of 8/27, the radar was tested at the Salton Sea using the 2.5 degree antenna. The Salton Sea was chosen because it was reasonably close to WaveBand's facilities, but offered higher numbers of large birds and a longer range for detection trials. Wildlife activity was generally within 500 m of the radar location, and consisted of a wide variety of waterfowl moving in all directions. However, pelicans, cormorants, and geese were seen at greater distances. While in the field, single birds (pelicans) were consistently seen as far away as a mile (1.6 km). In post-processing, signals that appeared to be single birds were seen at 2 km; another signal was seen at 2.3 km that appeared to be a small flock, but could potentially be a pelican. Flocks of birds were seen up to 2.3 km in post-processing, and there was one detection based on a very weak signal at 2.6 km of a flock of about 100 geese.